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THE USE OF X-RAYS AND CATHODE RAYS IN CHEMICAL AND METALLOGRAPHIC INVESTIGATIONS *)

by W. G. BURGERS.

539.26:539.72

Diffraction diagrams taken with X-rays or electron beams are capable of supplying information about the identity and essential characteristics of the structure of a material. After a brief statement of the fundamentals of the interpretation of such diagrams, the possibilities of the application of diffraction research in chemical and metallographic work are illustrated by means of a series of examples.

Introduction

One of the most powerful aids in the examination of the structure of matter is the refraction (diffraction) experienced by X-rays in passing through the matter. This phenomenon, like the diffraction of electron rays, which according to the insight of modern physics may in many respects be considered as a wave phenomenon analogous to X-rays, gives insight into the arrangement of the atoms (or molecules, as the case may be) in crystals. The information gained in this way may on the one hand be brought into connection with the nature of the binding forces between the atoms, and on the other hand with the properties of the crystal complexes built up therefrom.

In general, diffraction investigations can only produce such results in the hands of investigators who are completely at home in the crystallographic foundations of structure analysis and who have specialized in this subject. On the other hand, however — and this lends the method of diffraction analysis its great *practical* significance — many chemical and metallographic problems can be studied by this method and a solution can be reached without a deep knowledge of crystallography being required. This possibility is based upon the fact that in principle diffraction analysis of a substance gives data not only about the crystal-

lographic structure, but also about the crystalline state in which the substance exists and upon which many of its properties are found to depend, as well as about its chemical composition. As one of the characteristics of the crystalline state may be considered the fact as to whether the substance is built up of large or small crystal blocks, and further the state of perfection of the crystal blocks and their position in a given material. Changes in the crystallographic structure of compounds or alloys can often also be ascertained and related to changes in their properties, without it being necessary to call in the aid of crystallography proper.

Before illustrating the significance of these possibilities by means of several concrete examples, we shall first explain briefly how the information mentioned is obtained from the diffraction phenomena.

Foundations for the interpretation of diffraction diagrams

Spot photographs

The atoms of which a crystal is built up are, in an "ideal" crystal, arranged in a regular way upon groups of parallel planes which groups intersect each other (*fig. 1*) and are called crystal lattice planes. In each group two successive planes are at a definite distance apart. For a given crystal all these lattice plane distances are fixed, as also the angles between the various intersecting groups of planes.

If a beam of X-rays or electrons falls upon a crystal, the rays are scattered in all directions by

*) Editor's note: In the following article, with the consent of Prof. W. G. Burgers, we give the main content of the address delivered by him upon his acceptance of a professorship at the Technische Hoogeschool in Delft on January 15th 1940. Of the possibilities of application here reviewed, a number have already been dealt with in the first and second volumes of this periodical.

the atoms. Due to interference the scattered rays neutralize each other in general, except in very definite directions. Fortunately for our power of imagination these directions may be described as those in which the primary beam of rays would be reflected if the lattice planes were mirrors.

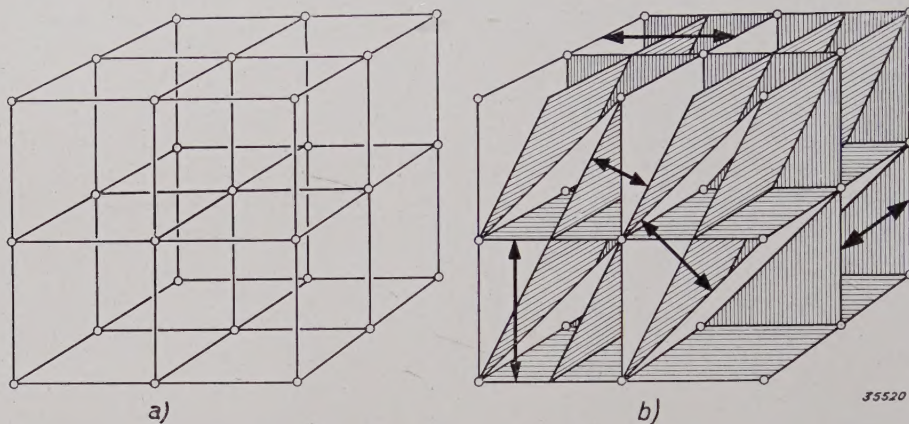


Fig. 1. The atoms are regularly arranged in a crystal according to a lattice, a simple type of which is here represented (a). The atoms in such a lattice may be imagined as arranged upon groups of mutually parallel planes which intersect each other at definite angles. Several planes of five of these groups (there are of course many more) are shown here (b), with the corresponding lattice plane distances.

Upon a photographic film placed around the crystal, therefore, in addition to a central spot produced by the unscattered rays of the primary beam, a very definite pattern of spots will be formed. Such a so-called Laue photograph is shown in *fig. 2*. From this pattern, on the basis of the above-mentioned simple mirror relation, the position of all the crystal lattice planes with respect to the direction of radiation can be derived. In this way, therefore, the crystal lattice can be analyzed, or — what is more important at the present moment — the position of the lattice (expressed crystallographically: the position of the crystal axes) can be ascertained.

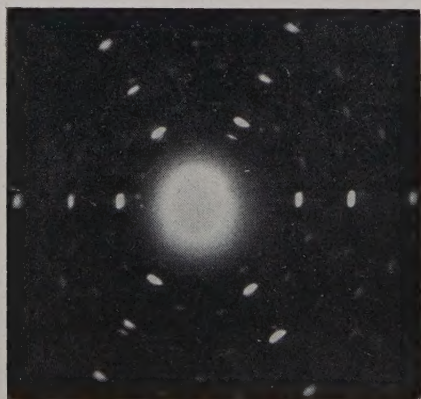


Fig. 2. Spot pattern obtained by the diffraction of a beam of X-rays through a single crystal (Laue photograph).

For the formation of such a spot pattern the external boundary of the crystal is a matter of indifference to a certain extent. Thus if a substance is irradiated which consists of a collection of larger or smaller crystalline fragments with irregular boundaries, each of these so-called crystallites will

give rise to a spot diagram. In the case of most ordinary materials the individual crystallites are so small that the beam of X-rays ¹⁾, which may have a diameter of $\frac{1}{2}$ mm for example, falls upon several at once. The diffraction diagram then exhibits a superposition as it were of a number of separate spot patterns. If the position of the crystallites in the substance under examination is entirely random as far as the orientation of their crystal lattices is concerned, then the spots are distributed more or less uniformly over the whole photograph as may be seen in *fig. 3a*. If, however, the crystallites have definite preferred positions, that is if the substance shows a texture, then the spots are collected in definite groups, each of which corresponds to crystal lattice planes of the same "kind" belonging to the different, approximately similarly oriented crystallites. *Fig. 3b* is an example of such a photograph. The mean position of the crystallites with respect to the boundary of the substance, *i.e.* the crystallographic character of the texture, can again be ascertained by means of the above-mentioned simple mirror relation between spot and lattice plane.

The smaller the crystallites in the substance, the greater the number which will be struck simul-

¹⁾ For the sake of brevity we shall here and in the following speak only of X-rays. Electron rays can also generally be understood.

taneously by the X-ray beam, and therefore the greater the number of spots on the photograph. At the same time the intensity of every spot decreases

rise to elongated spots on the photograph (see fig. 5), whose length and position can give us some information about the nature of the crystal defect.

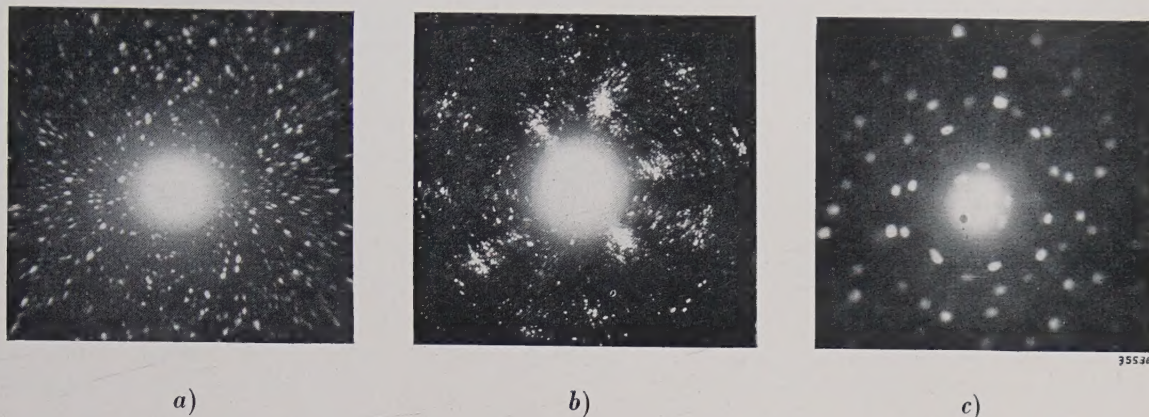


Fig. 3. Spot photographs. Upon simultaneous radiation of a number of crystallites a superposition of all the spot patterns is obtained. With random positions of the crystallites the spots are spread over the whole photograph (a), when there are preferred positions the spots are collected into groups (b). While in (a) 20 to 30 crystallites are irradiated at the same time (fine crystalline substance), in (c) there were only a few (coarse crystalline substance).

in general with the size of the reflecting crystal lattice plane. Information about the size of the crystallites can thus be deduced from the spot diagram. This is illustrated by a comparison of fig. 3a and c which show the contrast between a fine and a coarse crystalline substance.

The crystallites of which a substance consists are themselves often built up of small regions which are not absolutely parallel but join each other at a small angle (fig. 4). This is true of every crystal to a certain extent, due to irregularities in the process of growth. The phenomenon occurs much more pronounced in plastically deformed crystals, where, due to the sliding of parts of the crystal along one another, rotation and bending of crystal lattice planes by 10° or more may occur. Just as a circular spot is stretched out to a line or otherwise upon reflection in a curved mirror (familiar to every one from the distorting mirrors at fairs, etc.), in the same way the reflection of X-rays at the curved lattice planes of such an imperfect crystal will give

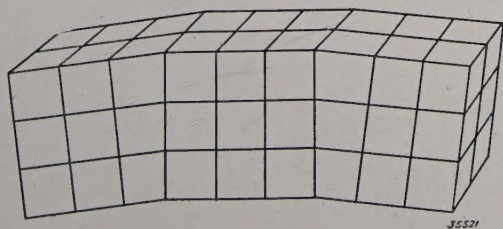


Fig. 4. Imperfect crystal built up of small contiguous lattice zones lying at small angles to each other. The lattice planes of the crystal are bent, as it were.



Fig. 5. Spot diagram of an imperfect crystal.

Circle diagram

In the foregoing it is tacitly assumed that every lattice plane, no matter at what angle the X-rays are incident, can reflect the X-rays. This is, however, not always true. The "reflection" of an X-ray takes place at a whole group of mutually parallel lattice planes at once (fig. 6). If the reflected ray is to possess an observable intensity, all these reflections must reinforce each other by interference, i.e. the difference in length of the path of rays reflected at different planes of the group must be a multiple (n) of the wave length (λ). From this follows the condition

$$2d \sin \Theta = n \cdot \lambda, \dots \dots (1)$$

$$n = 1, 2, 3, \dots,$$

where d is the lattice plane distance characteristic of the lattice plane, and Θ is the angle between lattice plane and X-ray beam. If the beam of X-rays is polychromatic, i.e. if it contains rays of a whole

range of wave lengths, then for each combination d , Θ , i.e. for every lattice plane present, there are rays whose wave length satisfies equation (1), so that every plane gives rise to a spot on the diffraction

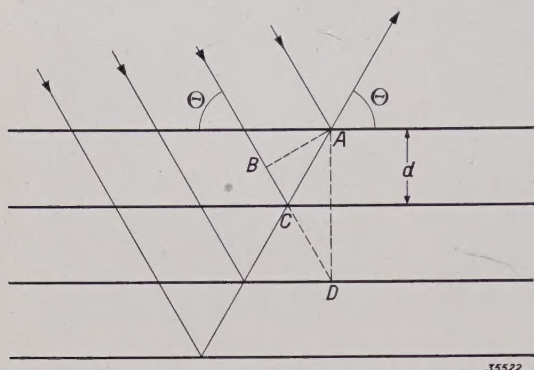


Fig. 6. The refraction of the X-rays may be considered as a reflection at the lattice planes in which all the planes of one group work together. In order that the reflected ray may not disappear due to interference, the difference in trajectory $BC + AC$ must be an integral multiple (n) of the wave length λ . Since $CD = CA$ the difference of trajectory is equal to the side BD of the right triangle DBA where $DA = 2d$ and the angle $BAD = \Theta$. Formula (1) follows from this.

photograph. In this way we obtain the spot diagrams discussed above. If, however, the X-ray beam is monochromatic, i.e. if all the rays have the same wave length λ , reflection at a given kind of lattice plane can only occur when the angle Θ at which the X-rays strike the lattice plane fits the given combination d , λ . Therefore if the monochromatic X-ray beam strikes a single crystal, many fewer or even no spots at all will appear on the photograph. If the X-ray beam simultaneously strikes a large number of crystallites in which the lattice plane under consideration is in each case at a different angle to the beam, all those crystallites will contribute to the reflection in which this angle satisfies equation (1). Reflected X-rays can therefore only occur at angles of 2Θ with respect to the beam, where Θ is given by equation (1). The scattered X-rays therefore all lie on a number of cones having apex angles of 4Θ , see fig. 7, which intercept the photographic film in a series of concentric circles or rings. In the case of sufficiently finely crystallized preparations the spots lie so close together on these circles that they give the impression of continuous rings.

Since each circle corresponds to a definite lattice plane distance, and, as already mentioned, a very definite group of lattice plane distances belongs to a given crystal, the circle system is characteristic of the crystal lattice under consideration, and in general it is different for every substance. In this way the monochromatic diffraction photograph

may be used simply for the identification of a substance, either element or compound. In the presence of different kinds of crystals (different phases) in the same preparation the different ring systems corresponding to them occur at the same time in the diffraction diagram, so that they make possible an analysis of the mixture.

At the same time, however, the circle diagram is able to provide other valuable information. Because of the fact that the diameters of the rings (angles Θ) are directly connected with the lattice plane distances (d) a slight change in those distances will manifest itself in a corresponding change in the ring diameters, and thus in a shifting of the rings. Such changes in the lattice dimensions may occur for example due to elastic strain or by the taking up of substances in solid solution.

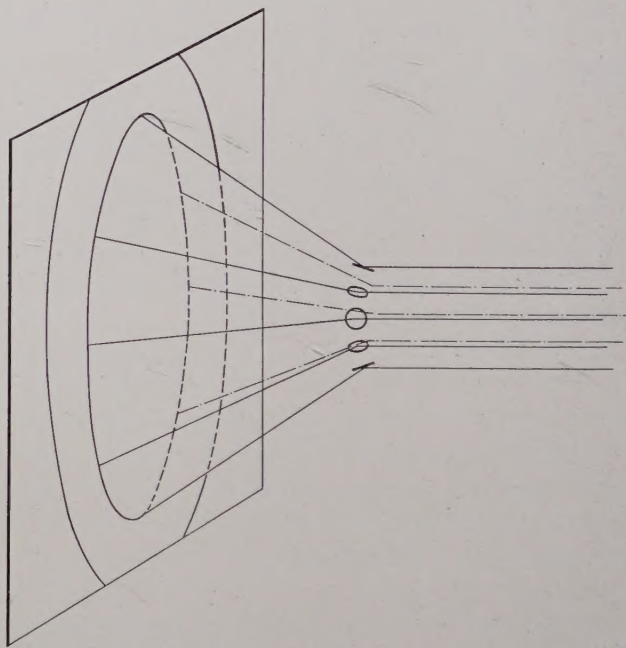


Fig. 7. The formation of circle diagrams. In a polycrystalline substance upon which a monochromatic X-radiation falls, only those crystallites are active as "reflectors" in which the lattice planes are at angles Θ to the beam according to equation (1). The rays reflected at a particular type of lattice plane therefore all lie on a cone with the apex angle 4Θ .

Finally the circle diagram like the spot diagram is able to provide data about the size and degree of perfection of the crystallites, and about the occurrence of preferential orientations. Only when a very large number of crystallites is struck by the beam will the circles appear continuous, as stated above, (fig. 8a); when the number is smaller, i.e. when the crystallites are larger, every ring is resolved into a number of spots (fig. 8b), whose number and definition permit an estimation of the size of the crystals. In the presence of texture, the

spots are again collected into definite groups, *i.e.* the intensity of the diffraction rings varies along the circumference (fig. 8c). The intensity of the

give much sharper pictures. On the other hand the penetration of electron rays is very slight for the same reason, so that the information obtained with

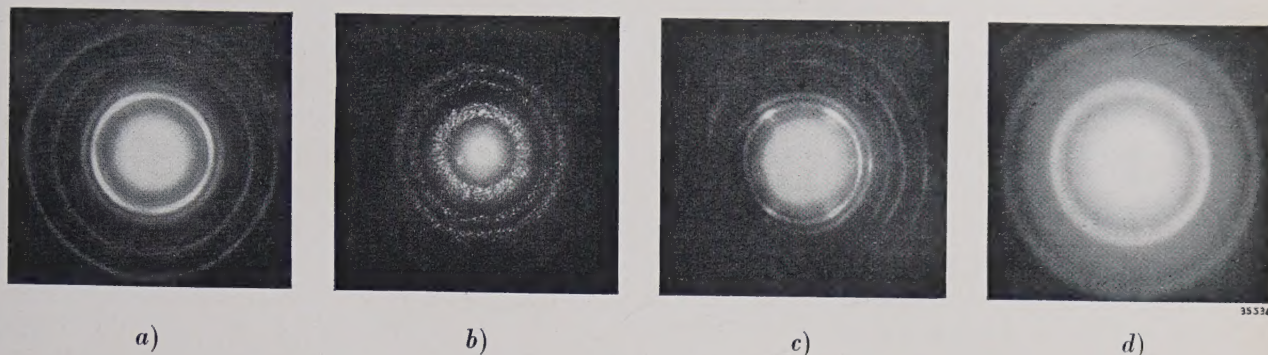


Fig. 8. Circle diagrams: a) rings continuous and sharp; b) rings decomposed into points: presence of larger crystallites; c) rings with varying intensity along their circumference: presence of texture; d) rings not sharp: crystal defects.

diffraction lines and in some cases their definition can also be influenced by crystal flaws (fig. 8d), according to whether the flaws are spread over many or few atoms.

A lack of definition in the diffraction diagram may also occur due to a quite different cause, namely when the number of atoms collaborating in the scattering is very small. In such cases the investigation with electron beams offers a welcome supplementary method.

Diffraction of electron beams

Fundamentally the same considerations are valid for electron beams as were given above for X-rays; they are therefore to provide similar information about the state and the chemical character of a crystalline substance. Due, however, to their much stronger reaction with the atoms, electron beams give a clear diffraction picture with much smaller amounts of substance than are required for the refraction of X-rays, and consequently, with the same amounts of substance, electron beams

their help relates only to the state of the substance in very thin layers, a few atoms thick.

In fig. 9a the electron diffraction picture is given of an extremely thin gold foil (obtained by etching away). The great sharpness of the rings is striking. Fig. 9b shows a similar diagram of an aluminium foil, in which it may be concluded from the variations in intensity around the circumference that there is a texture.

Possibilities of practical application

We shall now illustrate by a number of examples the different possibilities of application of diffraction analysis which follow from the foregoing. These applications may be divided into two main groups. In the first group the problem is that of the nature or composition of a substance, in the second, of the crystalline state in which it exists.

Nature and composition of a substance

Identification of a compound

The simplest application is that for the identification of a compound. For example, by characterizing the ring diagram of each compound by giving the angles of refraction and intensities of the three strongest lines ²⁾, a kind of table for determination can be obtained. Such tables have been made by Hanawalt, Rinn and Frevel ³⁾, among

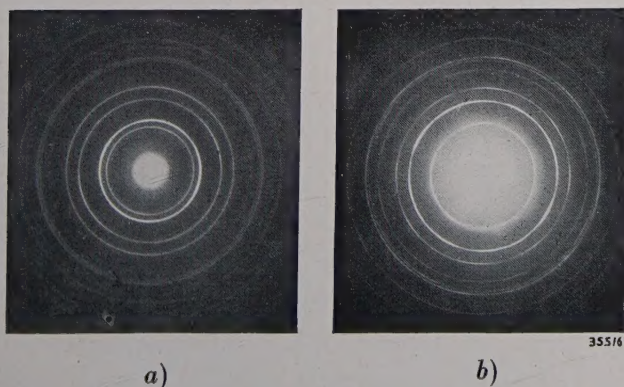


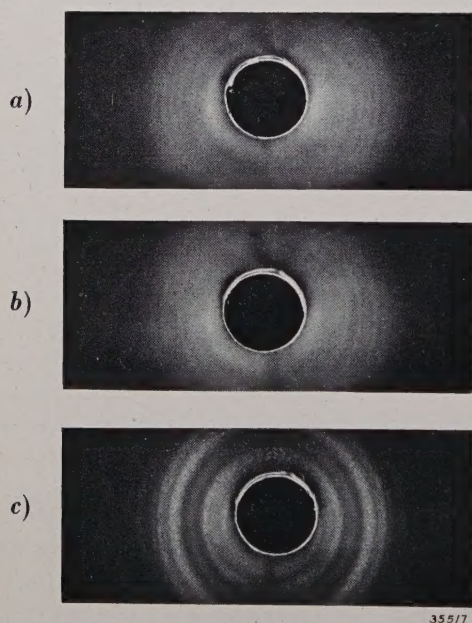
Fig. 9. Electron diffraction diagrams: a) of an extremely thin gold foil, b) of aluminium foil with obvious texture.

²⁾ If it is only a question of the diameter of the rings (and not for instance of the variation in intensity around their circumferences) it is sufficient to photograph a narrow strip passing through the centre of the system. Instead of complete circles one then obtains a number of more or less curved lines on the photograph.

³⁾ J. D. Hanawalt, H. W. Rinn and L. K. Frevel, *Ind. Eng. Chem.* **10**, 457, 1938.

others, for a relatively large number of compounds (1 000). Due to all kinds of factors, however, such as differences in the crystalline state of the samples used, changes in intensity, etc. may occur which make the use of the tables difficult if not impossible. In general therefore it is better to compare the diagram obtained from the unknown substance with self-made diagrams of comparison substances. In the case of investigations in a given laboratory the choice of comparison substances to be considered will usually be limited to a relatively small number of repeatedly occurring substances of which a collection of diagrams can be prepared in advance.

As an example of an identification on these lines we may mention a case of an organic compound, namely an osazone obtained by Meuwissen and Noyons⁴⁾ in their investigations of the occurrence of vitamine C in urine. The X-ray diagram of this compound was found to be identical with that of the osazone of ascorbic acid (vitamine C) and quite different from the X-ray diagram of the osazone of reductinic acid (see *fig. 10*) which is built up chemically in an analogous way to a certain extent. This result confirmed their assumption that vitamine C occurs in normal urine.



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Fig. 10. Comparison of the diffraction patterns of the osazone *a)* of the product isolated from urine, *b)* of ascorbic acid (vitamine C) and *c)* of reductinic acid.

It is particularly in organic chemistry where the identification by means of diffraction diagrams is still only little used, that this method, in addition to identification by determination of melting point or other methods, deserves more attention. Only

a small amount of material is needed for making the diffraction diagram, ten milligrams for instance. The X-ray diagram, filed with the sample investigated, may also be of use later on, in order for example to ascertain any change or decomposition of the substance. Isomers (if crystalline) can also be distinguished from each other in this way in spite of their identical chemical composition. The diagrams of ortho- and paradioxybenzene for instance differ plainly from each other.

If the amount of a preparation available is smaller than that mentioned as necessary for making an X-ray diagram, an examination with electron rays — as explained above — may offer a solution. By this method it was found possible to obtain an excellent line diagram with only a few crystal needles of the acetate of a provitamine D obtained from an animalic product by Boer, Reerink and van Wijk⁵⁾. The ring system was practically identical with that which was obtained from the acetate of synthetic 7-dehydrocholesterol. (Upon continued investigation it was found that ergosterol acetate, which is related in atomic composition, gives only a slightly different diagram, so that in this case the diffraction test could not provide absolute proof of the identity of the synthetic and the natural product. This identity was, however, established by another method.)

Analysis of a mixture

If the material to be examined consists of a mixture of different substances, the diagram, as previously mentioned, exhibits the lines belonging to the various components of the mixture, and from it therefore, again by comparison with known diagrams, the composition of the mixture can be deduced qualitatively, and to a certain extent quantitatively also, by estimating the relative intensities. The significance of the analysis obtained in this way is that it gives us the compounds and not, like purely chemical analysis, the atomic composition. By this method, for example, it was possible to find out whether thorium oxide, which is added to the original tungsten oxide in the preparation of metallic tungsten for electric lamps, is present as such in the metallic tungsten after the reduction process or has also been reduced to the metal — a question which was of great practical importance in connection with recrystallization phenomena in the filament⁶⁾. Another practical

⁴⁾ T. Meuwissen and E. Noyons, *Acta brevia Neerlandica*, **8**, 35, 1938.

⁵⁾ A. G. Boer, E. H. Reerink, A. van Wijk and J. van Niekerk, *Proc. Roy. Acad. Amsterdam* **39**, 622, 1936.

⁶⁾ *Z. anorg. allg. Chem.* **193**, 144, 1930; see also *Philips techn. Rev.* **1**, 188, 1936.

example is furnished by the investigations carried out at the Agricultural High School in Wageningen on the composition of clay minerals ⁷). In the case of just such complicated compounds (silicates) where the chemical analysis gives only little information about the actual structure, the diffraction method may be particularly useful.

Investigation of solid solutions

The possibility of identification also renders X-ray analysis a valuable tool in the study of reactions in the solid state, which are otherwise approached only with difficulty. If the reaction products form new phases they can be recognized by their line systems; if, however, they are taken up in solid solution in the original phase, an expansion or contraction of the crystal lattice is the result, which is manifested in a gradual shift of the original lines. The change in lattice-plane distances can be calculated from this shift, and the approximate quantitative composition of the solid solution can often be deduced ⁸). In metallurgical laboratories the determination of phase limits is being carried out in this manner to an increasing extent.

As an example of a reaction in which a new phase as well as a solid solution could occur we may mention here the research on tantalum carbide wires ⁹), which might be used as filaments in vacuum lamps. Such wires, which are made by heating carbon filaments in tantalum halide vapour, were found to exhibit great differences in electrical resistance and in rate of evaporation (blackening of the bulb). Chemical analysis is difficult because of the insolubility of the carbide, and moreover it destroys the test filament. With X-ray diffraction pictures on the other hand it was easy to ascertain that the less suitable wires contained the carbide Ta₂C in addition to the carbide TaC, while in some cases the metal itself was present in solid solution in the carbide. The remedy for the latter evil was simple; by subsequent heating of the wires in an atmosphere of methane the excess of tantalum was converted into the carbide TaC.

The absorption of gases in metals may also be studied to some extent with the help of diffraction analysis. A good example of this occurred in an investigation by de Boer and Fast ¹⁰)

on the mobility of oxygen in zirconium under the influence of an electric field. The metal is able to take up a large quantity of oxygen in solid solution (up to 40 atom per cent). The dimensions of the crystal lattice as well as the electrical resistance increase with the oxygen content. If a direct current was sent for some time through a zirconium wire containing oxygen, the resistance of the section of wire in the neighbourhood of the positive pole was found to increase considerably — visible directly by the lighter glowing of this section — while the resistance near the negative pole decreased at the same time. This phenomenon must, according to the investigators mentioned, be ascribed to the fact that the oxygen moved toward the anode through the zirconium lattice, probably as a negative ion, under the influence of the electric field, and there increases the concentration of oxygen. The diffraction diagrams of the parts of the wire in the neighbourhood of the poles did indeed indicate an increase in the lattice distances at the anode and a decrease at the cathode, in agreement with the above-mentioned interpretation of the phenomenon as an "electrolysis in the solid state".

Finally the possibility of the investigation of diffusion processes in solid substances may be mentioned in this connection. Due to the limited depth of penetration of the X-rays used in diffraction analysis, the information which the diffraction diagrams provide about the composition relate only to the outermost layer of the substance examined, which is 10 or 20 microns thick, for example. If the surface layer is removed by etching and a new X-ray diagram is made, any deviation in the composition of the surface layer, caused by diffusion can be brought to light. With electron rays even much thinner surface layers (oxide films, for instance) can be determined and identified in this way.

Crystalline state

While the applications of diffraction analysis mentioned until now may be considered more or less as supplementary to analyses carried out by purely chemical methods, it is quite a different matter with the applications in which the character of the crystalline state is in question. It should be stated in advance that the knowledge of the crystalline state, i.e. of the size and state of perfection of the crystallites, their orientation, etc. may be of great importance, since a large number of the properties of materials, such as electrical conductivity, photochemical behaviour, chemical activity, cohesion, can be considerably influenced even by relatively slight changes in the crystalline state.

⁷) C. H. Edelman, F. A. van Baren, J. Ch. L. Favejee and H. J. Hardon, *Mededeelingen van de Landbouwhoogeschool te Wageningen* 43 (1939), *Verhandeling* 4-6.

⁸) See for example *Philips techn. Rev.* 1, 220, 1936.

⁹) See *Philips techn. Rev.* 1, 253, 1936.

¹⁰) J. H. de Boer and J. D. Fast, *Rec. Trav. chim. Pays Bas* 59, 161, 1940.

The determination of such a correlation implies not only an increase of knowledge but it may often also be of practical significance when the properties in question are themselves difficult to measure, or when, as in manufacturing processes, they can only be revealed after the process has already proceeded too far.

Size and state of perfection of the crystallites

Of the many cases where information is required about the size and state of perfection of the crystallites, we shall in the first place mention the investigation of the chemical activity of various substances. Hoffmann and co-workers¹¹⁾ found that preparations of carbon and soot were most active when they consisted of very small crystallites or of crystallites with a very much distorted lattice. Such pieces of information are able to serve as guides in the preparation of these materials for technical use.

In the case of another substance of quite a different nature, namely butter, attempts were made to obtain information from the X-ray diagram about the state of the crystallized component, in the hope of being able to find a relationship between differences in solidity of kinds of butter prepared in different ways and differences in the size of the butter-fat crystals, which were to be expected on the basis of other considerations. Although our preliminary tests gave no clear answer to the question¹²⁾, in principle it does not seem impossible that more extended investigations of this nature may be of value in the study of questions in the chemistry of foodstuffs.

Orientation of the crystallites

Layers of metal or salt deposited by evaporation, or sputtering or electrolytically often exhibit an anisotropy in their properties. This is found to be connected with the fact that the crystallites are oriented in definite preferential directions, which can be studied by means of diffraction analysis. Such a texture can be shown for example in the case of nickel layers electrolytically deposited¹³⁾, where on the one hand certain properties such as adhesion and brilliance are found to be correlated with the texture, while on the other hand the occurrence and nature of the texture are found to depend in a complex manner on the thickness of the layer and

the condition under which the electrolysis was carried out, such as current density, size of the electrolysis vessel, stirring, etc.

Another interesting example of X-ray analysis of texture is the investigation of the orientation of the cellulose crystallites in the wood of violins of different sound quality¹⁴⁾. It was found here that while in all cases examined the belly of the violin exhibited a pronounced texture as shown by the X-ray diagram, such a texture in the back of the violin occurred only in the case of the less good violins; in the better class instruments it was practically absent (*fig. 11*).

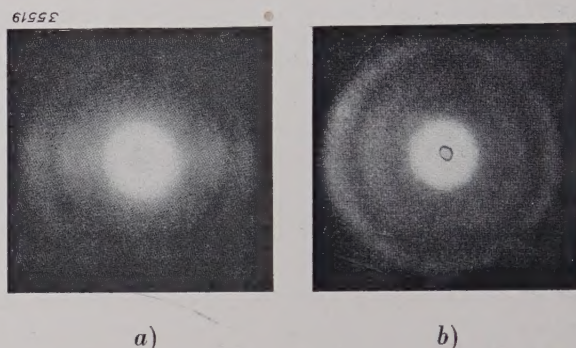


Fig. 11. In the back of violins of poor sound quality the cellulose crystallites show evidence of texture (a), which is absent in the case of violins of good quality (b). (From Lark-Horowitz and Caldwell, *Naturwiss.* **22**, 450, 1934).

An orientation of the crystallites also occurs regularly in the working of metals. The crystallites in drawn wire and rolled sheet always assume certain preferential positions; by heat treatment following the working, in which new crystals are formed by recrystallization, these preferential positions can be entirely modified. The texture leads to an anisotropy in the properties of the metal which may be either desired or undesired for the purpose in view. A good example of a desired anisotropy obtained by working is that of the rolled nickel-iron strip for cores of loading-coils, diffraction diagrams of which are reproduced in *fig. 12* and explained in the text under the figure¹⁵⁾. An undesired anisotropy is often encountered in the punching of caps and sockets out of rolled sheet-iron. It leads to the formation of a lip¹⁶⁾. The determination of these textures by X-ray methods and of their crystallographic nature may be very valuable for the sake of the indications it gives as to desirable alterations in the process of working.

¹¹⁾ U. Hofmann and D. Wilm, *Z. Elektrochem.* **42**, 504, 1936.

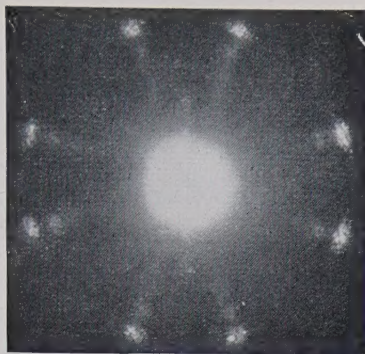
¹²⁾ W. van Dam and W. G. Burgers, *J. Dairy Sci.* **18**, 45, 1935.

¹³⁾ See *Philips techn. Rev.* **1**, 95, 1936.

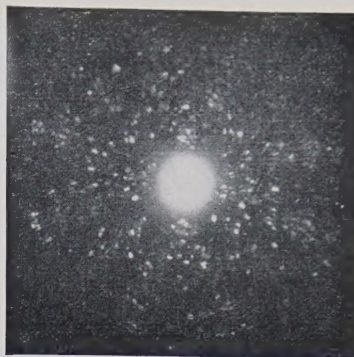
¹⁴⁾ K. Lark-Horowitz and W. I. Caldwell, *Naturwiss.* **22**, 450, 1934.

¹⁵⁾ For a more detailed discussion see *Philips techn. Rev.* **2**, 93, 1937.

¹⁶⁾ *Philips techn. Rev.* **2**, 158, 1937.



a)



b)

Fig. 12. Cores for loading coils are made of nickel-iron strip with strongly anisotropic magnetic properties. The desired anisotropy is obtained by rolling and recrystallization, which results in a pronounced texture. By means of X-ray photographs the process can be controlled at an intermediate stage of the treatment to find out whether (a) or not (b) the required texture has been attained.

Lattice distortions in metals

The pronounced property of metallic crystals of being deformed plastically also involves the fact that not only the orientation but also the internal state of the crystallites may undergo great changes during working and heat treatment, *i.e.* lattice distortions occur in and among the crystallites. These distortions differ from the above-mentioned crystal defects in that they are accompanied by internal tensions in the deformed metal which are in turn of influence on many practically important properties such as electrical resistance, mechanical hardness, magnetizability, etc. Such lattice distortions and conditions of strain also occur in the separation of one component out of a super-saturated solid solution.

The investigation of lattice distortions by means of the broadening and changes in intensity of the lines or spots in diffraction diagrams is a particularly good sphere of application in which the diffraction method may not only serve in routine control tests (for instance, for the presence of internal strains) but where it can also contribute to the knowledge of phenomena which have not yet been explained scientifically. An interesting and technically important example of this are the recent investigations¹⁷⁾ of the differences between so-called cold-hardened and warm-hardened copper-aluminium alloys. The metal aluminium can take up several per cent of copper in solid solution at 500 °C; at 200 °C it cannot take up more than a few tenths of a per cent. By quickly cooling an alloy which has been saturated at a high temperature to room tem-

perature, however, the homogeneous state is, as it were, fixed. The alloy is now mechanically soft. The hardness, however, is found to increase slowly again, to a maximum value which is reached in the course of several days (so-called ageing, cold hardening). If the alloy, after having reached its maximum hardness, is heated for instance to 200 °C, a decrease in hardness at first takes place, and after longer heating a new state of hardness occurs (warm hardening). These phenomena can now be correlated with the occurrence of lattice distortions resulting from the diffusion processes which initiate the separation of the excess copper atoms present. Diffraction diagrams of single crystals of the alloy immediately after the rapid cooling from the high temperature exhibit, in addition to well-defined points, some poorly defined stripes also which increase in clearness and definition during the ensuing ageing¹⁷⁾. Closer analysis of these stripes showed that they must be ascribed to the appearance of small plate-like aggregates of copper atoms, several atoms thick at the most, along the sides of the tubes of the crystal lattice, and it must be assumed that this beginning of aggregation is already accompanied by an increase in hardness. Upon heating to 200 °C a disappearance of the stripes in the diffraction diagram, together with the decrease in hardness, occurs at first. The aggregates thus redissolve. The increase in hardness upon longer heating is again accompanied by the re-appearance of the stripes which now, however, are much sharper, and thus indicate the formation of considerably larger copper aggregates. After still longer heat treatment the stripes break up into sharp points, from which it may be concluded that the plate-like aggregates grow to still larger complexes.

¹⁷⁾ G. D. Preston, *Phil. Mag.* **26**, 855, 1938; A. Guinier, *Thèses*, Paris 1939.

With this example we wished to illustrate how differences in technological properties of alloys treated in different ways can be reduced to differences in internal structure. In doing this we have wandered somewhat from the validity of the thesis which was stated at the beginning of this paper: that the diffraction method can be successfully applied, even without a deeper knowledge of the

crystallographic foundations of the science of structure. We hope, nevertheless, that it will have appeared from the series of applications here summed up that the sphere in which our thesis holds is sufficiently extensive to insure diffraction analysis an important position among the research methods with technical application.

TECHNICAL PHOTOMETRY OF GAS-DISCHARGE LAMPS

by P. J. ORANJE.

535.24 : 621.327.4

In order to control the manufacture of gas-discharge lamps an apparatus was designed which makes it possible to carry out measurements on gas-discharge lamps in a reliable, rapid and inexpensive manner with an accuracy of 3 per cent in the light flux. The apparatus consists of 18 photometers which can be read from a central point. The time necessary to heat up the gas-discharge lamp in the photometer can be used to measure lamps in other photometers.

When it is a question of measuring large numbers of sources of coloured light daily in the control of the manufacture of gas-discharge lamps, in addition to the problems which occur in the photometry of sources of coloured light in general¹⁾, there are also practical difficulties. After an explanation of these points we shall in this article discuss how the light flux of gas-discharge lamps is deter-

mined in a technical way in the control laboratory of the Philips factories.

Statement of the problem

In contrast to a research laboratory a control laboratory in general carries out measurements on only a limited number of types of lamps. As a rule, however, a large number of lamps of the same type must be measured successively. The light flux of these lamps must be known under conditions such as occur in practical use. One does not deter-

¹⁾ See: Physical Photometry, Philips techn. Rev. 4, 260, 1939; The Photometry of Metal vapour lamps, Philips techn. Rev. 1, 120, 1936.

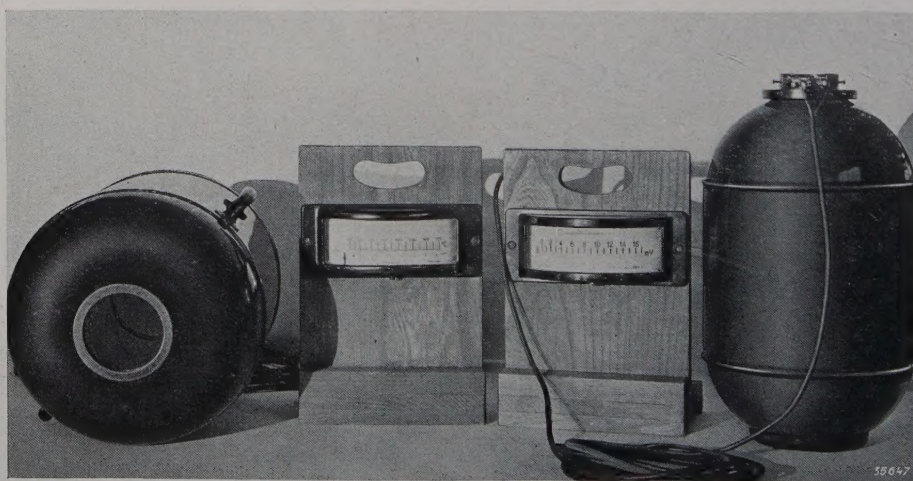


Fig. 1. Two small portable integrating spheres, photographed in different positions.

mine therefore (as is often done in scientific research) the light flux for a definite current or for a definite power of the lamp, but the light flux which occurs when the lamp is connected to a certain, accurately known apparatus in series on a main of a certain voltage, and when it has been in operation long enough to have reached the state occurring in permanent operation. This heating time for gas-discharge lamps may amount to from 15 to 30 min.

It is chiefly this long time for heating up which is experienced as a difficulty in control measurements of gas-discharge lamps. If the lamp is allowed to burn in the photometer during the whole time of heating up, the photometer is "occupied" much longer for every measurement than is necessary for the measurement itself. If, however, the lamp is not inside the photometer while heating up, then for every measurement either the lamp to be measured must be moved to the photometer or the photometer to the lamp, which involves difficulties which will be explained in the following.

Against the moving of the lamp the following points may be advanced:

1) Shocks, which easily occur during the transportation of the lamp, may cause the light flux of some kinds of gas-discharge lamps to change. Particularly in the case of sodium lamps a displacement of the liquid sodium in the lamp may lead to a permanent change in the light flux.

2) Some gas-discharge lamps (especially mercury lamps) do not reignite immediately after an interruption of the supply voltage, so that the current may not be interrupted during the transport from the rack where the lamp burns to the measuring table. This involves great complication of the installation with much chance of poor contacts, wear and tear, etc.

The objections to the moving of the photometer to the lamp are more serious than those to the moving of the lamp to the photometer:

1) In connection with the requirement that the measurement must take place rapidly, it is desirable that an objective measurement with the help of a light-sensitive element should be carried out. This means, however, that the apparatus contains very delicate components. Due to shocks or jars the

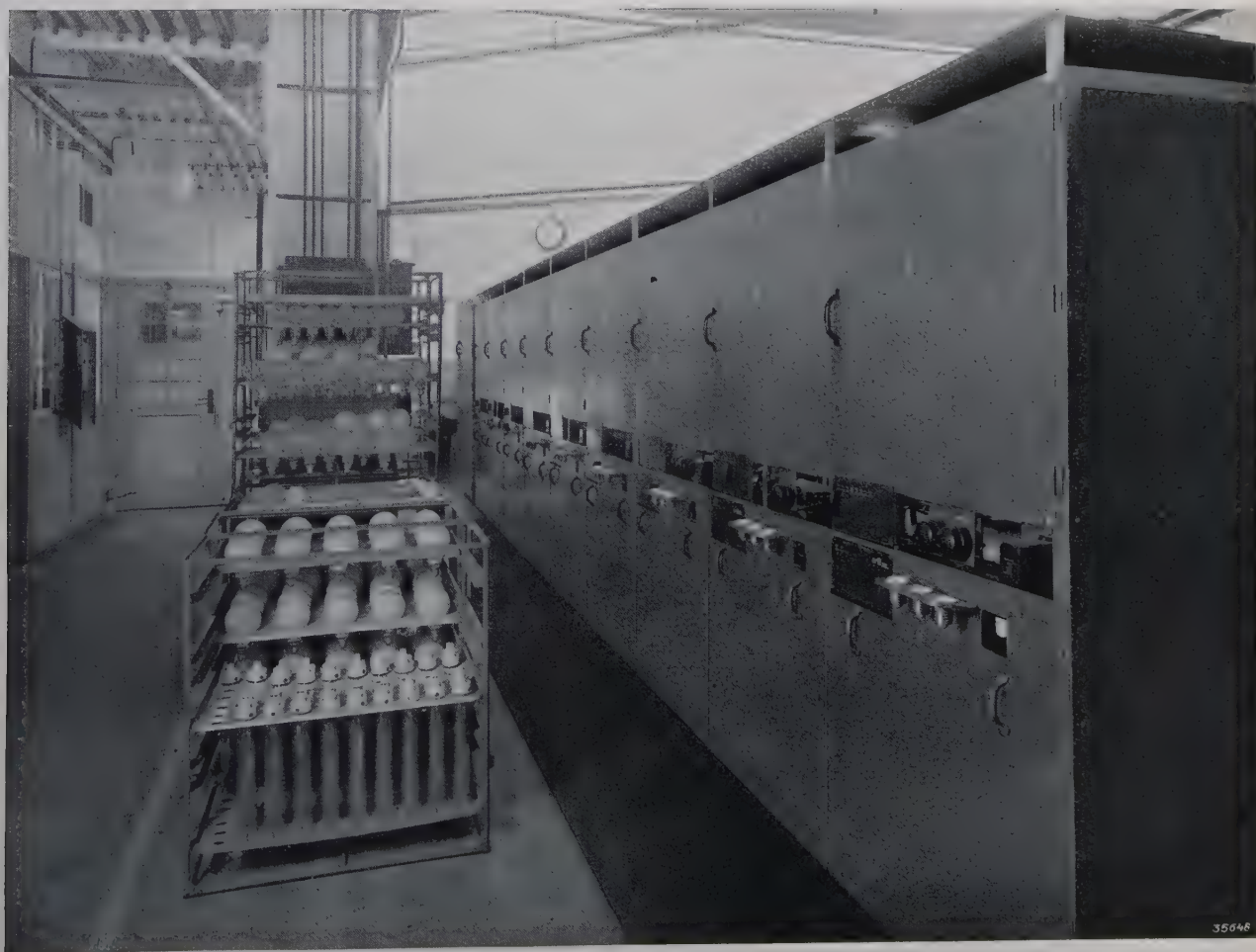


Fig. 2. Row of nine photometer chambers intended for routine measurements of gas-discharge lamps. The whole installation consists of two such rows.

element can be slightly displaced or damaged, the contacts may also suffer, etc.

2) The sphere of a transportable photometer must be small (see *fig. 1*). This means that the result is no true measure of the light flux, but also depends upon the light distribution of the lamp, so that for instance slight deviations in the shape of the lamp or socket, imperfect centering of the lamp, etc. may have considerable influence on the results of the measurement. Moreover during the measurement the small sphere becomes appreciably warm, which may have a noticeable effect upon the reflective properties of the internal surface and upon the sensitivity of the photo-element. Experience has shown that, due to these influences, even with daily calibration it is practically impossible to reach a greater accuracy than about 8 per cent with a portable photometer sphere.

In order to avoid the objections mentioned, in the installation to be described below a large number of photometers were set up side by side, so that the lamp can heat up in the photometer sphere itself, and neither the measuring apparatus nor the lamp need be moved. In order to facilitate the measurement the installation was so arranged that the results can be read off at a central point. Before proceeding with the technical execution of the installation we shall first discuss how the problems which are inherent in heterochromic photometry were solved in this special case.

Principle of the photometric method employed

As stated, the light flux of the lamp to be measured is determined with the help of an integrating photometer. In this photometer is a screen whose brightness is measured by means of a photo-element. The ratio between this brightness and the light flux of the lamp to be measured is determined by calibrating the photometer with a standard lamp with known light flux.

If the spectral composition of the light of the comparison lamp deviates from that of the gas-discharge lamps to be measured, the ratio of the photocurrents which are obtained with these two lamps is only a measure of the ratio of the light fluxes when the spectral sensitivity curve of the light sensitive element corresponds to the international eye-sensitivity curve. Two measures are therefore taken.

Firstly a highly sensitive element is used whose spectral sensitivity is to some extent adapted to that of the eye ²⁾. Secondly the deviations, which occur due to the fact that the correspondence between the spectral sensitivity of the photo-

element and of the eye is not perfect, — together with other errors which may occur in the measurement with a photometer sphere — are considerably reduced by using the installation only for the comparison of lamps of the same type. The colour adaptation of the photo-element need therefore only be carried so far that the colour differences between individual gas-discharge lamps of the same sort do not cause any noticeable error.

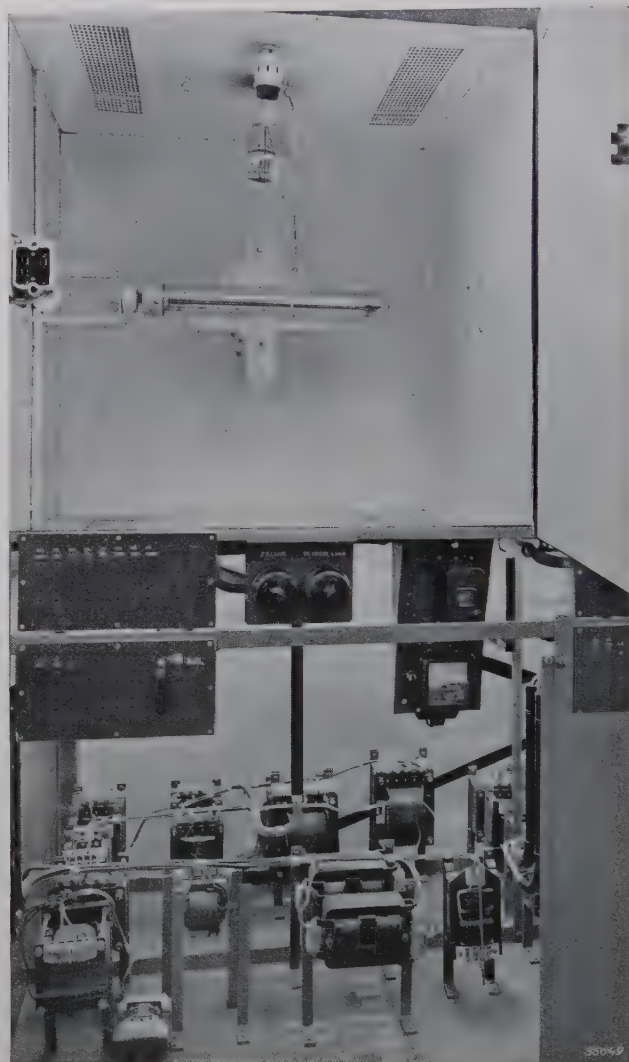


Fig. 3. An opened photometer-chamber. Through the bulb of the electric lamp may be seen a socket, to the left on the wall a second socket for the gas-discharge lamp to be measured. The latter contains a sodium lamp. Below the chamber to the left the switchboard by which various apparatus may be connected in series; in this case the apparatus for the sodium lamp SO 1000. In the middle the switches for the electric lamp and lamp to be measured, on the right the time relay. Below the various series of apparatus for different types of gas-discharge lamps.

²⁾ According to Dresler such a photo-element can be realized by a selenium barrier-layer cell and several filters placed side by side slightly overlapping in front of the cell. By changing the regions which are covered by one or more filters, the spectral distribution of the sensitivity can be given the desired character. See for instance A. Dresler, *Das Licht* 3, 41, 1933; J. Rieck, *Das Licht* 7, 115, 137 and 157, 1937.

Construction of the installation

The installation is composed of 18 integrating photometers. For the sake of simplicity they are not spherical as is common, but cubic (edge 0.9 m) and placed in two rows of 9 "back to back". *Fig. 2* gives a view of the installation. The part below the switches contains a number of accurately known apparatus to be connected in series, while the part above the switches forms the photometer chamber proper. In *fig. 3* one of the photometers may be seen open. On the upper surface of the photometer chamber there is an electric lamp which serves for control of the photometer, which process will be discussed later. Behind this lamp and on one of the side walls two lamp sockets are mounted and connected in parallel, so that it is possible to let the lamp to be measured burn either in a horizontal or

a vertical position. Between these lamp sockets and the supply mains, by means of a special plug-in contact in the switchboard below the photometer, any one of the above mentioned apparatus can be connected in series. Upon shutting the door the circuit in which the lamp is included is closed, while the contacts are always free of tension when the door is open.

In the upper and lower planes of the photometer strips of perforated metal have been set in. At the back of the chamber is the photo-element, which is shielded in the usual way from direct light.

By means of two rotating switches all the connections of every photometer can be switched over to the central measuring table which is shown in *fig. 4*. One exception is the connection for the current of the photo-element. In order to avoid disturbances which may easily occur at the very low voltages



Fig. 4. Measuring table of the installation. The vertically placed instruments measure the mains voltage and the current (when a transformer is used, primary and secondary separately). The instruments placed obliquely on the table measure the total power. The left-hand horizontal meter measures the photo-current, the right-hand one the voltage on the contacts of the lamp. To the right on the table may be seen the handles of the rotating switches, each of which serves part of the photometer cabinets. To the left on the table a series of switches for the photo-elements of the different photometer chambers. Above the meters are the neon lamps which glow when the heating time of the corresponding lamp has ended.

of barrier-layer photo-elements, this connection is by means of a separate cable to a separate switch-board on the measuring table.

When the door of the photometer is shut a time relay (see fig. 3, to the right below the photometer) is switched on, and after a previously chosen length of time it lights a numbered neon lamp on the measuring table. This is the sign to the operator that the lamp has burned long enough for the measurements to begin. On the other hand the operator at the measuring table can signal back to the person working at the photometer that the lamp has been measured.

A measurement proceeds as follows. A calibrated lamp of the type to be tested is first placed in the photometer. The time relay is set at the necessary heating time, and the door is shut. As soon as the neon lamp of the photometer chamber in question ignites at the measuring table, the operator there determines the photo-current, then switches off the gas-discharge lamp and switches on the electric lamp and again determines the photo-current. From the relation between these two photo-currents the apparent light flux of the electric lamp can be calculated.

After this calibration of the photometer chamber the calibrated gas-discharge lamp is replaced by the similar gas-discharge lamp which is to be measured, and this is measured with the electric lamp as standard lamp. The installation is best operated by two persons: one changes the lamps and the other does the measurement.

The light flux of the electric lamp found will in general differ slightly from the true light flux, be-

cause the colour adaptation of the photocell is not perfect. This is, however, of no importance since the error is exactly compensated when the electric lamp is subsequently used as standard lamp for the measurement of a series of gas-discharge lamps of the same type. In principle the electric lamp could be omitted and the gas-discharge lamp compared directly with the calibrated model. The introduction of the electric lamp, however, has the advantage that this light source, which is permanently available, very constant and rapidly put into action, makes it easy by means of occasional checks, to take into account any change in the sensitivity of the photometer, so that the calibration of the photometer need not be repeated for several weeks at a time.

As already stated, thanks to the fact that comparative measurements are carried out exclusively on a single type of lamp, the influence of numerous sources of error (selective reflection of the inner wall, irregular distribution of the light radiation in different directions, difference between the sensitivity curve of photo-element and the eye, casting of shadows by the lamp, etc.) is reduced to a minimum. The accuracy attained, which may be estimated to be within 3 per cent, may indeed be considered high for routine measurements.

The capacity of the installation depends upon the nature of the lamps to be measured and is determined chiefly by the time for heating. For example about 75 HP-lamps (small air-cooled mercury lamps) can be measured per hour, while for sodium lamps the number is much smaller, since sodium lamps must cool in the photometer after the measurement until the sodium has solidified.

**VIEW OF A PART OF THE INDUSTRIAL PLANT OF N.V. PHILIPS' GLOEI-
LAMPENFABRIEKEN, EINDHOVEN**



A NEW PUSH-PULL AMPLIFIER VALVE FOR DECIMETRE WAVES

by M. J. O. STRUTT and A. van der ZIEL.

537.543:621.385

For the reception of signals with wave lengths shorter than 1 metre electronic valves are needed with very low input and output damping, steep slope and low noise resistance. The so-called acorn pentode satisfies the first requirement but fails to satisfy the last two. In order to satisfy these last requirements electrode systems with larger dimensions must be used. At frequencies above 10^8 cycles/sec., however, such systems possess too great input and output damping. It is shown in this article that the input and output damping of such systems can be considerably lowered by connecting two systems in a push-pull circuit in a suitable way. After an explanation of the construction and properties of the push-pull amplifier valve EFF 50 developed on this principle, the possibilities of its employment are dealt with. In particular a discussion is given of the results which can be obtained upon application of this valve in amplifying and mixing stages.

Methods of measurement have been developed in this laboratory in recent years by which currents, voltages and impedances at very high frequencies (up to about $1.5 \cdot 10^9$ c/s. corresponding to a wave length of 20 cm) can be accurately determined. These measurements have in the first place been applied to electronic valves in order to investigate the behaviour of these valves in detail¹). On the basis of the insight obtained, new valves have been developed which give better results at very high frequencies than those used until now. After an explanation of the limitations in the application of the existing electron valves the construction and properties of one of these new types of valves, namely the push-pull amplifier valve EFF 50, is discussed in detail.

The function of an electron valve

The electron valve serves in general to amplify the incoming signal and to transmit it in some form or other to the following stage. In the case of a high-frequency amplifier, for instance, the requirement is that the character of the voltage transmitted shall be a faithful enlarged image of the incoming voltage within a certain frequency region. In the case of a mixing stage, on the other hand, it is desired that the modulation of the transmitted voltage shall have the same character as the modulation of the input voltage, while the character of the voltage itself is quite different; the latter has, namely, a much lower frequency than the input signal.

In addition to the quantitative requirement of a satisfactory enlargement of the amplitudes, there is the qualitative requirement that the desired relation between output voltage and input voltage shall be realized as fully as possible. According to

whether the amplitude of the input voltage is very large or very small, two kinds of deviations may here occur. At very great amplitudes due to the curvature of the valve characteristics, the relation between input and output voltage, or between input and output modulation, deviates from true proportionality, or, in other words, distortion occurs. The relation is thus indeed unambiguous, but does not have the desired form. At very small amplitudes the reserve is true: the above mentioned distortion does not occur, but the relation between input and output voltage is no longer absolutely sharp: with a fixed input voltage the output voltage may still exhibit certain fluctuations, which are caused by incidental phenomena in the valve. If these fluctuations are of the same order of magnitude as the signal voltage obtained at the output, there can no longer be the least question of a relation between input and output voltage. These fluctuations, which are usually called noise, thus set a lower limit to the input voltage at which the valve can be used²). Since this limit is found to be of essential significance for the usefulness of a receiving installation, we arrive at the conclusion that, as far as the function of an electronic valve is concerned, *the valve must amplify as much as possible and give as little noise as possible.*

In the following we shall see how far valves of ordinary construction are capable of fulfilling this function.

Specification of the requirements made of electronic valves

The amplification of an electronic valve can be expressed quantitatively by four quantities which connect the output voltage and current with the input voltage and current. This is done by

¹) M. J. O. Strutt: *Moderne Kurzwellen-Empfangstechnik*, Verlag Springer 1939; *Moderne Mehrgitter-Elektronenröhren*, 2nd edition, Verlag Springer 1940.

²) The factors which determine the noise of a receiving set were dealt with in detail in a previous article (M. Ziegler, *Philips techn. Rev.* **3**, 189, 1938).

means of the equations:

$$\begin{cases} i_a = A v_g + B v_a \\ i_g = C v_g + D v_a \end{cases} \dots \dots \dots (1)$$

which have been given and discussed previously in this periodical³⁾. A , B , C and D are in general complex quantities depending upon the frequency: they are called the characteristic admittances of an amplifier valve. The admittance A is nothing other than the slope of the valve, B is the output admittance, C the input admittance and D the reaction admittance. If the admittances are known, the amplifying properties of the valve can be calculated in every connection. The noise properties are however not given thereby, and must be considered separately.

The most efficient way of characterizing the noise of an electronic valve is by the introduction of the concept of noise resistance. The definition of noise resistance is based upon the fact that a "noise voltage" appears in every resistance, *i.e.* that at its extremities certain voltage fluctuations occur due to the thermal motion of the electrons in the interior of the resistance. In effective magnitude these fluctuations are proportional to the square root of the resistance value and the temperature. By the noise resistance R of an electronic valve is understood that resistance whose voltage fluctuations (at room temperature) are of the same magnitude as those voltage fluctuations which would have to be introduced between grid and cathode of an electronic valve in order to cause the anode current to fluctuate as much as actually occurs due to the noise of the valve.

If we now return to the function of the electronic valve, it may be seen immediately from the above that it is desirable to make the slope A as steep as possible and the noise resistance R as small as possible. In order to understand the influence of the output admittance B and the input admittance C , we must consider the connection in which the valve is used. From equation (1), however, it follows immediately that the real parts of these admittances give rise to energy losses at the output and input ends, which is undesired in principle, so that it is important to make these admittances as small as possible.

Special cases

We shall confine ourselves here to the special case of high-frequency amplification, making a distinction between

- 1) the high-frequency amplifier stage of a cascade amplifier (two identical stages following one another), and
- 2) the high-frequency amplifier stage of a super-heterodyne receiver (which is followed by a mixing stage).

We may begin by dealing with both together with reference to the scheme represented in *fig. 1*. The input and output circuits are formed by tuned oscillation circuits with the impedances Z_1 and Z_2 . In parallel with Z_1 is the input impedance $1/C_1$. In parallel with Z_2 is the output impedance $1/B$ and, *via* the transformer T , the input impedance $1/C_2$ of the following stage. Although $1/Z_1$, $1/Z_2$, C_1 , B and C_2 are in general complex, we shall in the following always confine ourselves to the real parts, since by correct tuning of the circuits the imaginary parts can always be made to compensate each other.

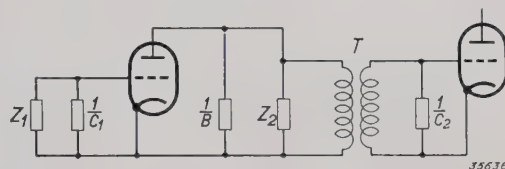


Fig. 1. Diagrammatic representation of a high-frequency amplifier stage connected to a second stage *via* a transformer T . Z_1 and Z_2 are the impedances of the input and output circuits, respectively, of the first stage; C_1 and C_2 are the input admittances of the first and second amplifier valves, respectively, B is the output admittance of the first amplifier valve.

If the amplification, *i.e.* the relation between the output voltage E_u and the input voltage E_i of the given circuit, is calculated for a transformation ratio n , one finds:

$$\frac{E_u}{E_i} = \frac{A n}{n^2 C_2 + \frac{1}{Z_2} + B}.$$

This expression as a function of n has a maximum for $n^2 = (B + 1/Z_2)/C_2$, and the maximum amplification amounts to:

$$\frac{E_u}{E_i} = \frac{A}{2 \sqrt{\left(B + \frac{1}{Z_2}\right) C_2}} \dots \dots (2)$$

It is often possible to make $Z_2 \gg 1/B$. On this condition:

$$\frac{E_u}{E_i} = \frac{A}{2 \sqrt{B C_2}}.$$

If $2 \sqrt{B C_2} > A$, the ratio E_u/E_i becomes less than unity, and there is therefore no longer any ampli-

3) See in this connection the article by M. J. O. Strutt, and A. van der Ziel, Philips techn. Rev. 3, 103, 1938.

fication possible. If a given amplification is desired, for instance by a factor v , the condition

$$\sqrt{BC_2} < A/2v \dots \dots (3);$$

holds for the input and output admittances, and it may therefore be seen that the two admittances may not exceed a certain magnitude.

As to the noise, it is more difficult to reach a numerical formulation of the requirements made. These requirements depend of course entirely upon the intensity of the available input signal. We may, however, state that a decrease in the noise of electronic valves is only of importance as long as this disturbance is not weak compared with the noise due to other sources. Besides the electronic valves it may be seen in the figure that there are other sources of noise, namely the impedances Z_1 , $1/C_1$, $1/B$, Z_2 and $1/C_2$.

Let us first consider the noise from the first amplifier valve and the first oscillation circuit. In fig. 1 we see that between grid and cathode of the first valve the impedances Z_1 and $1/C_1$ are in parallel with each other, thus at the same spot as the imaginary noise resistance R . From this it follows that the noise from this noise resistance R must be small compared with the noise of the two impedances Z_1 and $1/C_1$ connected in parallel. If this condition is satisfied, the contribution of the first valve to the noise is small compared to that of the other sources of noise mentioned. This requirement thus indicates an upper limit for the noise resistance R . If we now consider first the case where $1/C_1$ is large compared with Z_1 our requirement amounts to

$$R \ll Z_1.$$

When, however, Z_1 is large compared with $1/C_1$ one would expect as condition

$$R \ll \frac{1}{C_1}$$

From a more detailed consideration it is found that in the last condition C_1 must be replaced by C_e , *i.e.* by that part of the input admittance which is due to the transit time of the electrons. The calculation, which we shall not reproduce here, shows that the product RC_e is a measure of the maximum value of the ratio between signal voltage and noise voltage which can be obtained by adapting the first stage to a given aerial. The larger this product, the less useful the valve.

Until now we have given the requirements for making the noise due to the first valve as small as possible compared with the noise from the input circuit. If we now make the requirement that the

noise properties so obtained shall suffer as little disadvantage as possible from the following stages, it is found that a lower limit must be set to the amplification of the first stage. We must now make a distinction between the cases (1) and (2) mentioned above.

In case 1) (cascade amplification) the input resistance and noise resistance of the second valve are about as large as those of the first valve, the same is thus true of the fluctuations which occur in the second stage.

When we represent the total fluctuations of valve plus circuit of each stage by a noise resistance R_t , the noise resistance which, connected to the input of the first stage, represents the noise of both stages together, amounts to:

$$R_t + \frac{R_t}{v^2},$$

where v is the amplification. If v has the value 3, for example, the total noise resistance at the input of the first stage becomes only about 10 per cent greater due to the presence of the second stage, and the equivalent voltage fluctuations become only 5 per cent greater, since these fluctuations are proportional to the square root of the noise resistance. In cascade amplification, therefore, an amplification of 3 must be considered as sufficient in connection with the noise.

In the case of a mixing valve in the second stage, the total noise resistance of this stage is generally considerably greater than with a high-frequency amplifier valve in the second stage, for instance, a factor 10 greater. If the requirement is again made that the influence of the second stage on the noise shall be appreciably less than that of the first stage, the amplification must be made considerably higher, 5 to 10 times instead of 3 times.

Limitations of electronic valves at high frequencies

In the foregoing we have stated the requirements which must be met by the admittances of an electronic valve if it is to fulfil its function. Passing on to higher frequencies it becomes more and more difficult to fulfil this requirement.

As has been explained in detail in the article quoted about the behaviour of electronic valves, while the slope A remains unchanged, at least in absolute value, up to very high frequencies, both the input and the output admittances (we refer always to the real parts) increase steadily with increasing frequency, usually proportional to the square of the frequency. The result is that the left-hand side of equation (3) becomes steadily

larger with increasing frequency, so that the equation no longer holds for valves of ordinary construction for frequencies above about 10^8 cycles/sec.

The cause of the undesired increase in input and output admittance lies, as explained in the article referred to, in two phenomena:

- 1) the finite transit time of the electrons between the electrodes in the valve;
- 2) the self-inductions and mutual inductions of the connecting wires of the various electrodes.

If it is desired to keep the input and output admittances small at high frequencies, therefore, it is necessary to combat these two phenomena.

The acorn pentode

A very obvious method of decreasing the inductive effects and the transit times is to diminish the dimensions of the valve. The result of the technical development which took place in this direction several years ago is the so-called acorn pentode, whose admittances are given in *fig. 2* as functions of the frequency.

The acorn pentode may be used for amplification purposes up to about 2×10^8 c/s. (1.5 m). At this frequency the input admittance C is $1/4\ 000\ \Omega$, the output admittance $B = 1/10\ 000\ \Omega$ and the slope $A = 1.4$ mA/V. With the help of equation (3) it may be calculated that at this frequency an amplification is possible by a factor

$$v = A/2\sqrt{BC} = 4.6.$$

If, in agreement with experience, it is assumed that

the admittances increase with the square of the frequency, then for the case of cascade amplification ($v = 3$) an upper limit of about $2.5 \cdot 10^8$ c/s. (1.2 m) can be calculated.

The noise resistance of the acorn pentode amounts to about 8 000 ohms ⁴⁾. The product RC_e at $2 \cdot 10^8$ c/s is thus about 2, which may be considered tolerable. With increasing frequency, however, this product rapidly increases, so that as far as noise is concerned the application of the acorn pentode is subject to about the same limitations as set by the amplification.

A further reduction of the dimensions of the valve, which theoretically would mean an improvement, is at present not yet possible technically. Moreover it is very much a question whether the expected improvement would be realized. It is essential that the decrease in size of the valve should not result in a decrease in steepness of slope. Theoretically this requirement could be fulfilled, since the slope is entirely determined by the relations between the dimensions. Actually, however, there are a number of effects which, with decreasing dimensions, have an unfavorable influence upon the slope of a valve, so that the ratio A/\sqrt{BC} will increase little or perhaps not at all upon further reduction of the dimensions. In the present position of technology the acorn pentode must be considered as the most satisfactory compromise as far as the dimensions of the valve are concerned, so that it will not be possible to develop a valve in this direction which is suitable for the amplification of higher frequencies than $2 \cdot 10^8$ c/s.

On the principles discussed above we shall now point out a new line of development which will carry us farther than the line employed until now of decreasing all the dimensions.

A new type of high-frequency amplifier valve

As we have seen, for frequencies higher than 2×10^8 c/s. (1.5 m) it is desirable to have a valve with a steeper slope and a lower noise resistance than the acorn pentode. Valves with steep slope can be constructed by applying various devices. One of these is the enlargement of the surface of the cathode while keeping the distance between the electrodes in the valve constant. This method is analogous to the connection in parallel of a number of elec-

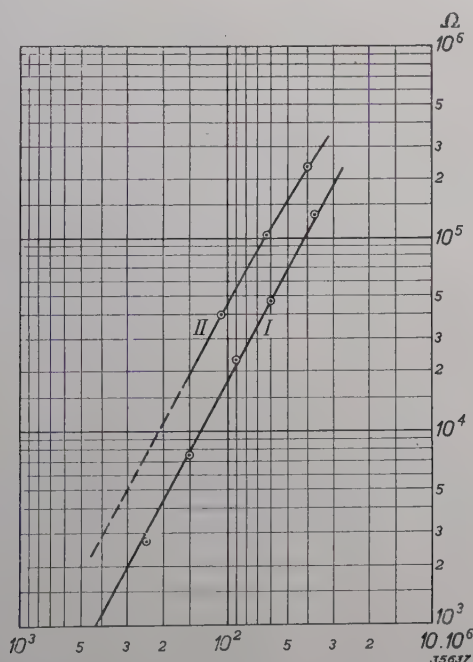


Fig. 2. Input resistance (curve I) and output resistance (curve II) of the acorn pentode 4 672 as function of the frequency in c/s.

⁴⁾ It must be noted here that the noise of a valve is actually somewhat stronger than is indicated by the above-mentioned noise resistance. With the high frequencies in question the intensity of the noise of the valve is a function of the impedance between grid and cathode. The above-mentioned value of 8 000 Ω holds for a very small value of this impedance.

trode systems. It therefore also leads to a decrease in input and output resistance so that no advantage is gained. When this method is eliminated there remains as second possibility the method used in the acorn pentode, namely by decreasing the distance between control grid and cathode, using at the same time a thinner grid wire and a lower pitch. In this case the input and output resistance need not become smaller. Starting with electronic valves of ordinary construction we have applied this second device. The distance between grid and cathode was reduced to 90 μ , and the slope thereby obtained amounts in the normal adjustment of the valve to 11 mA/V at an anode current of 10 mA.

An increase on the slope of a valve involves automatically a lowering of the noise resistance. The greater the slope the smaller the amplitude of the grid A.C. voltage necessary to cause a given fluctuation of the current. In the construction of the new high-frequency amplifier valve, however, an attempt was made to combat noise even more fully by decreasing the noise A.C. itself. This could be done by keeping the screen grid current low.

The fluctuations of the anode current in a pentode are caused partly by the fact that the electron current emitted by the cathode itself fluctuates, and for an important part also they are caused by the fluctuations of the current distribution between screen grid and anode⁵). The latter fluctuations may be kept small by providing that the screen grid current itself amount to only a small percentage of the total cathode current. In this respect an improvement was obtained in the construction in question by taking thinner screen grid wires and making the pitch of the screen grid greater than is usual in ordinary high-frequency amplifier valves. This has indeed as result that the screen grid fulfils its shielding function less effectively, but it is just the amplification at very high frequencies which is found to suffer no serious disadvantage from this.

The screen grid has the function of shielding the anode from the control, in order that a change in the anode voltage may have no influence on the anode current (high output resistance) and on the control grid voltage (small reaction).

In a valve of ordinary construction the output resistance is of the order of $10^6 \Omega$ at low frequencies. No advantage could be taken of such a high output resistance in the case of the amplification of very high frequencies, since the resistance of the tuned circuits connected in parallel amounts only to

⁵) See in this connection the article by M. Ziegler, Philips techn. Rev. 2, 329, 1937. In that article the phenomena which give rise to the noise in receiving valves are discussed in detail. From the discussion given the following formula can be derived for the noise resistance of a pentode:

$$R = \frac{4\,000}{S_a} \left[1 + 5 \frac{I_{g2}}{S_a} \left(\frac{I_a}{I_{g2} + I_a} \right) \right] \Omega,$$

where the value of the slope S_a must be substituted in mA/V and the anode current I_a and the screen grid current I_{g2} in mA.

several thousand Ω . As to the static output resistance, therefore, there is no objection to making the shielding between control grid and anode less effective than is usual in valves intended for lower frequencies.

The same result is reached as far as reaction is concerned. The reaction can be described by a capacity C_{ag} between control grid and anode, and is kept as small as possible by the screen grid. At high frequencies, however, the reaction is found to be caused to a large extent, not by the capacity between control grid and anode, but by the mutual capacities, self-inductions and mutual inductions of the various connections of the electrodes. The effect of this additional source has in many cases a greater absolute value and a sign opposite to that of the effect of the capacity C_{ag} . In these cases an increase of C_{ag} is immediately permissible and it even leads to a decrease in the total reaction.

By the decrease of the screen grid current, together with the increase in the slope, the noise resistance was reduced to 600 Ω , thus to about 1/13 of the value of the noise resistance of the acorn pentode. For the smallest input voltage to be amplified, which is proportional to the square root of the noise resistance, this means a gain by a factor 3.5.

As to the amplification, the improvement is even more important compared with the acorn pentode. The slope has increased from 1.4 to 11, thus by a factor 8, and when unput and output impedance are kept constant the same is true of the amplification.

The performance at high frequencies with the above-described construction is, however, not to be considered satisfactory. While the influence of the transit times will indeed be only relatively slight thanks to the short distance between control grid and anode, the inductive and capacitive effects of the connection wires are no smaller than in ordinary electronic valves, and these may have the well-known damping effect on the input and output circuit.

It has been found by measurements and calculations that this damping in the case of valves with steep slopes is mainly due to inductive effects of the cathode connections (inside and outside the valve) and is proportional to the slope. Since we are here concerned with a valve of very steep slope it is therefore necessary to combat the influence of the inductive effects of the cathode connections.

The push-pull amplifier valve EFF 50

The elimination of the inductive effects of the cathode connections is found to be possible by a special application of the push-pull principle. Two identical electrode systems fused together into a single bulb are provided as shown in fig. 3a with a common cathode connection. The voltage biases of

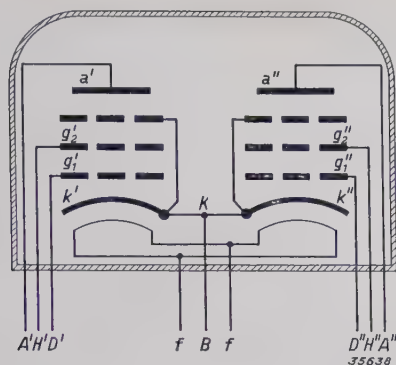
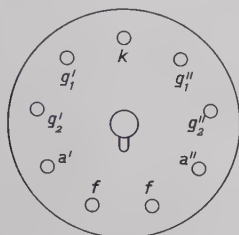


Fig. 3 a) Diagram of the electrode arrangement of the push-pull amplifier valve EFF 50. Two identical pentode systems with a common cathode connection B_k and indirect heating (ff) are mounted in an all-glass bulb.



b) Arrangement of the electrode pins in the base of the push-pull amplifier valve EFF 50.

corresponding electrodes are chosen equal, while the A.C. voltage of the control grid is supplied in opposite phase to the two halves of the system. The anode A.C.'s of the two halves of the system will then exactly cancel each other in part B^k of the cathode connection, so that inductive effects can only occur in the section $k'kk''$ of the cathode connection, which can be kept very short.

The input voltage acts over the terminals $D'D''$;

the resistance between these terminals may therefore be considered the input resistance. The input resistance is obviously twice as high as that of a single system. Moreover, due to the employment of the push-pull principle by which the connection wire B^k is rendered ineffective, the input resistance of each separate system is increased by a factor of about 2.5, so that a total increase of the input resistance by a factor 5 is obtained. The remaining part of the input damping must be ascribed chiefly to the transit time of the electrons between cathode and control grid. The output resistance between A' and A'' , which is affected to a smaller degree by the transit times of the electrons, amounts to even more than five times that of a single valve; it amounts, for instance, to ten times.

Another advantage of the push-pull principle is that the input and output capacities of the whole valve amount to only half of the capacities of each system separately, which makes these capacities not appreciably greater than in the acorn pentode.

Construction of the push-pull valve

A form has been chosen for the construction of the push-pull valve which is also used for modern receiving valves for ordinary broadcasting wave lengths, namely the so-called all-glass construction which has previously been described in this periodical⁶). This may be seen in fig. 4 together with several developmental models of different construction.

⁶) See the article: A new principle of construction for radio valves, Philips techn. Rev. 4, 162, 1939.

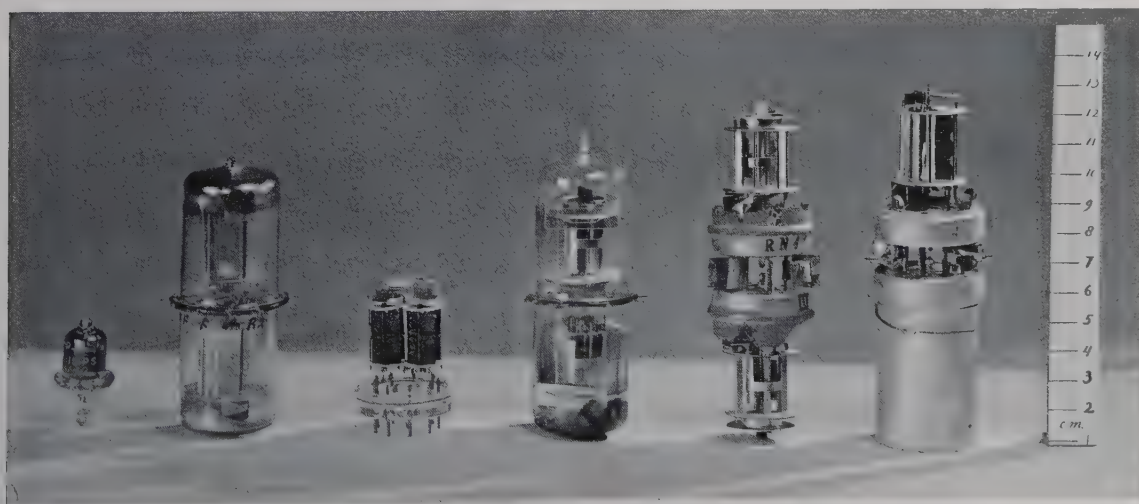


Fig. 4. Acorn pentode 4 672 (left) and a number of developmental models of the push-pull amplifier valve EFF 50. In the case of the first four of these models (second, fourth, fifth and sixth from the left) the systems are assembled end to end; in the final model (third from left) the systems are side by side. The two systems are surrounded not only by a glass bulb, but also by a common gauze cage which has been removed in order to show the assembly to better advantage. To the right a centimetre scale.

input impedance of the following stage becomes so low, even with a valve of the type EFF 50, that it is a serious obstacle to obtaining satisfactory amplification. It is found, however, that this damping can be eliminated to a large extent by including a self-induction in the screen connection. The A.C. voltage of the screen grid thereby generated produces, via the capacity between screen grid and control grid, a current in the control grid circuit which is opposite in phase to the control grid voltage, so that the real part of the input admittance is reduced⁸).

When the second stage is a mixing stage, care must also be taken that its input admittance is sufficiently high. Two diodes in push-pull connection

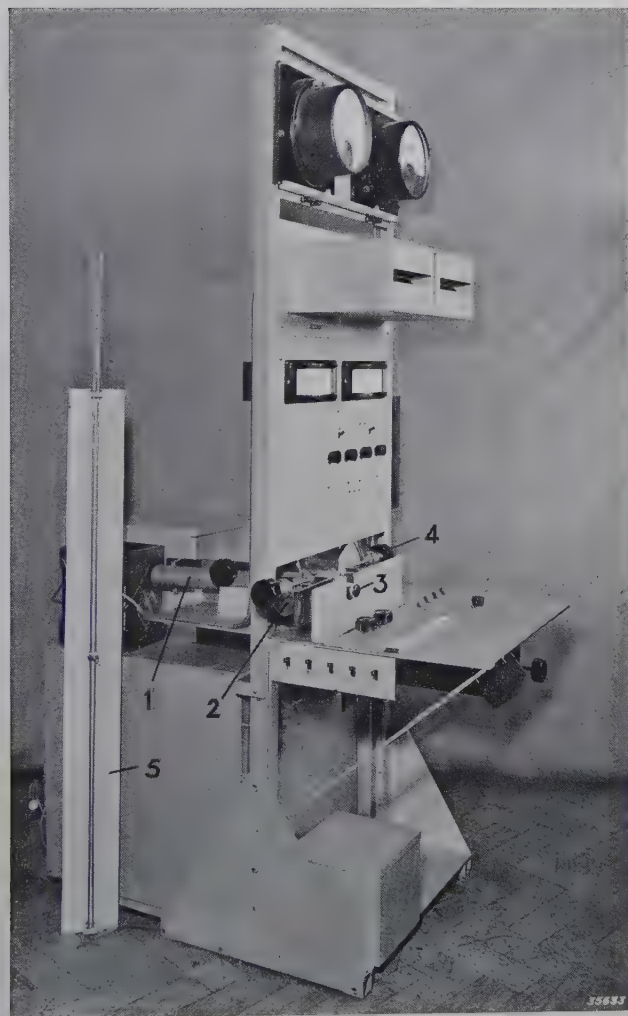


Fig. 7. Installation for the measurement of input and output admittance as well as amplification of push-pull valves at frequencies up to $6 \cdot 10^8$ c/s (50 cm). The meters at the top indicate the control grid voltages and the anode and screen grid currents. Underneath are two micro-ammeters, belonging to the diode voltmeters for the input A.C. voltages of the two control grids with respect to the cathode; below these, two similar micro-ammeters for the output end. 1 oscillator, 2 tunable input circuit consisting of two Lecher conductors with earthed covering; 3 valve to be measured; 4 tunable output circuit, 5 wave meter.

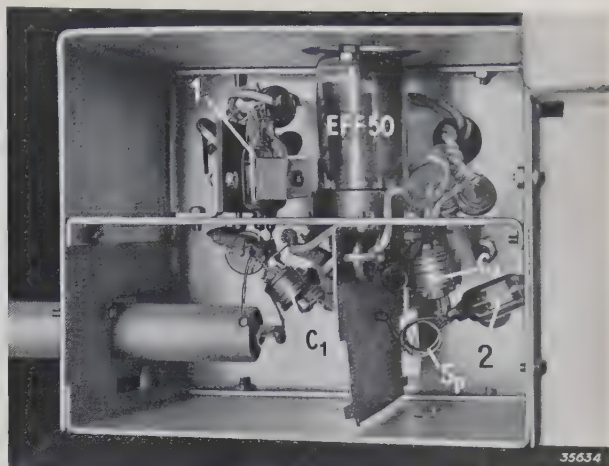


Fig. 8. Simple arrangement for the measurement of the amplification of push-pull valves in a circuit according to fig. 6 at a frequency of $3 \cdot 10^8$ c/s. 1 diodes for the measurement of the input A.C. voltage. 2 diodes for the measurement of the output A.C. voltage. The other symbols in the figure correspond to those of fig. 6.

may for instance be used as mixing stage, or one EFF 50 in a connection which will shortly be discussed. In both cases at a frequency of 3×10^8 c/s, a value of Z_u of about 3000Ω can be obtained. Since at this frequency the slope corresponds approximately to its static value of 11 mA/V , the amplification $v = \frac{1}{2} \times 11 \times 10^{-3} \times 3000 = 16.5$.

In testing this result experimentally a complication occurred which we shall discuss in detail, because it involves a point which may also be important in the practical application of the valve. If we consider fig. 6 we see that the input voltage as well as the output voltage is measured at the extremities of a coil. In the above calculation we have assumed that these voltages correspond to the voltages between the control grids g_1', g_1'' and between the anodes $a'a''$, respectively. For frequencies like those in question this is, however, not true, since the connecting wires of the coil to the grids (or anodes) possess considerable self-induction. This has already been pointed out in the discussion of the influence which the resistance of the grid connection pins has on the input damping, and we may use the substitute circuit, fig. 5, there derived in order to calculate the relation between the voltage E_i across the coil and the true input voltage E_i' between the control grids. If the series resistance r_s

⁸) In principle the application of this method is not limited to the push-pull amplifier valve, but offers a possibility of eliminating the input damping in the case of any amplifier valve. In practice, however, this method has the objection for most valves that the self-induction needed for a satisfactory lowering of the input damping is 20 to 30 times as great as with the push-pull valve EFF 50. Self-inductions of this order of magnitude, at the frequencies of decimetre waves, exhibit resonance phenomena which give rise to undesired effects.

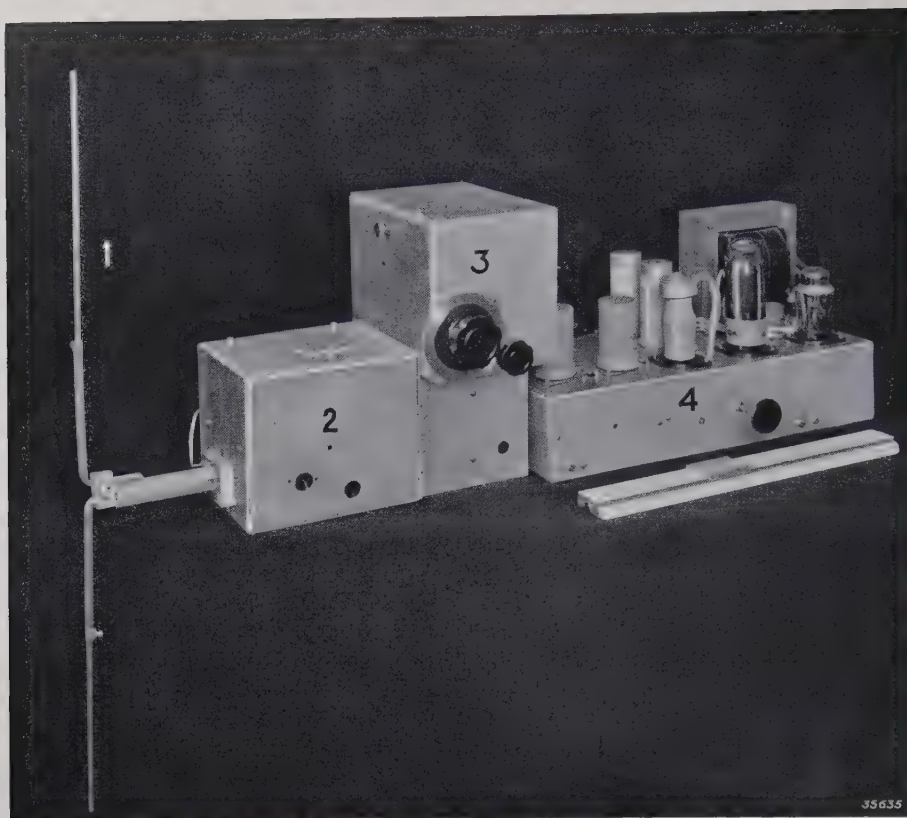


Fig. 9. Complete receiver for signals with a frequency of about $3 \cdot 10^8$ c/s. 1 dipole aerial; 2 box containing the circuit of fig. 6; 3 mixing stage; 4 intermediate and low-frequency part. To give some idea of the dimensions a slide rule about 25 cm long may be seen to the right.

is hereby neglected, we find for sufficiently large values of C_1 :

$$\frac{E_i}{E_i'} = 1 - \omega^2 L_s C_{kg}$$

and an analogous relation holds for the output end. It may be seen that the voltage at the extremities of the coil is in general smaller than the voltage between the electrodes.

As to the measurement of the amplification, the condensers C_1 and C_a were so chosen that in the input as well in the output circuit, at the frequency for which the amplification was being investigated, series resonance occurred between these capacities and the self-inductions of the connecting wires (about $4 \cdot 10^{-8}$ henries), so that the total impedance of the connection between the coil and the electrodes is zero. In that case E_i and E_u corresponds to the actual input and output voltages, respectively, so that equation (4) can be tested. The measurements were carried out with the help of apparatus especially developed for that purpose (see figs. 7, 8 and 9 with the text under the figures), and gave the theoretically expected results at frequencies of $3 \cdot 10^8$ c/s. It may be concluded from

this that, within the limits of the experimental error, which may be taken as about 5%, the slope of the valve does not change up to frequencies of $3 \cdot 10^8$ c/s. As stated, at a frequency of $3 \cdot 10^8$ c/s, an amplification by a factor 16.5 is obtained when an output circuit with an impedance of $3\,000\ \Omega$ is used. At a frequency of $5 \cdot 10^8$ c/s (60 cm wave length) the amplification might still amount to 8 under certain circumstances. These figures, which by no means represent an upper limit since impedances higher than $3\,000\ \Omega$ can also be realized, are appreciably larger than what can be attained with the help of the acorn pentode.

As for noise also, the push-pull amplifier valve is appreciably better than the acorn pentode. At a frequency of $3 \cdot 10^8$ c/s the electron part of the input admittance for the push-pull amplifier valve is $C_e = 1/600\ \Omega^{-1}$, while the noise resistance $R = 1\,200\ \Omega$, both values calculated between g_1' and g_1'' (see figs. 3a and 6). The acorn pentode, on the other hand, has at the same frequency an input admittance of $1/2\,000\ \Omega^{-1}$, almost entirely due to the transit times of the electrons, and a noise resistance of $8\,000\ \Omega$. The product RC_e , which, as already mentioned, determines the noise prop-

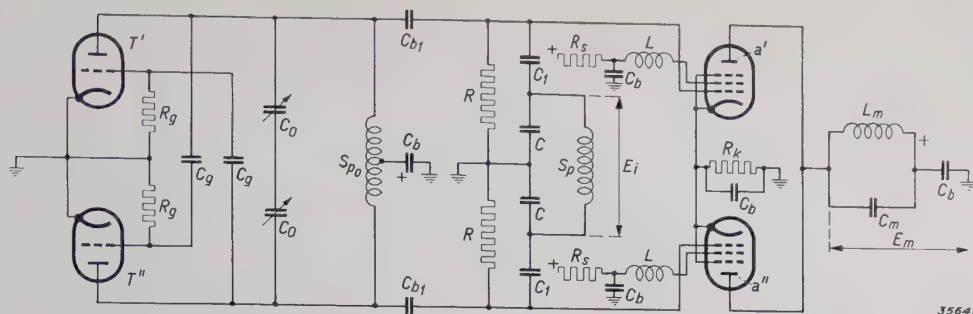


Fig. 10. Circuit of a mixing stage with the help of the push-pull amplifier valve EFF 50. The input voltage E_i is applied to the two control grids in opposite phase. The same is done via the small capacities C_{b1} with the oscillator voltage generated by the triodes T' and T'' . The necessary oscillator voltage is of the order of 1 V, while the necessary negative bias is 2 V higher than the oscillator voltage. The intermediate-frequency output voltage E_m is taken from the two anodes in the same phase with the help of the intermediate frequency circuit $L_m C_m$. R_g grid leakage resistances of the triodes; C_g grid condensers of the triodes; $C_0 C_0 S_{p0}$ oscillator circuit. The other symbols correspond to those of fig. 6.

erties of a valve⁹), therefore, in the case of the acorn pentode, in spite of its lower input admittance, is twice as unfavourable as in the case of the push-pull amplifier valve.

For the practical application of the push-pull amplifier valve it is very important to know whether or not any slight differences between the two halves of the valve which may occur during manufacture, are detrimental to the performance of the whole valve. This was investigated experimentally with the help of the measuring arrangement shown above. It was found that large differences in the anode currents (for instance 5 mA in one half and 15 mA in the other) cause the amplification, the input resistance and the output resistance to change by several per cent at the most.

This good performance may also be explained theoretically. Since at the high frequencies of decimetre waves the capacitive impedances between cathode, control grid and anode are small compared with the internal resistance of the valve, the anode A.C. in the two halves of the system will be exactly in opposite phase, if care is only taken that the external impedance of both systems with respect to earth is the same, and that the anode A.C. voltage varies exactly in opposite phase in the two systems. Both conditions can be satisfied by providing that the two halves of the coil S_p (fig. 6) are sufficiently strongly coupled with each other.

Although slight asymmetries have little unfavourable effect on the amplification of the valve, it remains nevertheless undesirable that one half of the valve should give much more direct current than the other half. This can be prevented by a suitable choice of the supply resistances of each of the screen grids (see fig. 6).

Application of the push-pull amplifier valve in mixing stages

In receiving sets it is also possible to use the valve EFF 50 as a mixing valve. Several different connections have been tried out for this purpose. One of these is shown in fig. 10. Several of the desirable properties of the valve, namely the slight noise resistance, the steep slope and the possibility of obtaining a high input resistance are also useful in this application. With the scheme of fig. 10, with suitably chosen voltages for each half of the valve, a so-called conversion slope of 2.8 mA/V can be obtained. This conversion slope indicates the ratio between the amplitude of the intermediate-frequency signal in the anode current and the amplitude of the high-frequency signal on the control grid. The amplification (intermediate-frequency output voltage divided by high-frequency input voltage) is, in the scheme shown, equal to the product of the conversion slope of one half of the valve and the impedance of the output circuit for the intermediate frequency used.

If the mixing stage is connected behind a high-frequency amplifier stage, it is desirable to make the input resistance of the mixing stage high by the use of self-inductions in the screen grid circuit, as was already explained.

The noise resistance of the push-pull amplifier valve when used in a mixing stage amounts to about 5 000 Ω between the input terminals, which may be considered unusually low. If the input resistance of the valve is increased to improve the amplification of the first stage, the noise of course also becomes stronger.

⁹) As we have seen the input resistance can be made very large by the introduction of a self-induction in the screen grid connection, and at first glance it might be supposed that a favourable influence might be exerted hereby on the ratio between signal and noise. This is found, however, not to be the case. Closer investigation shows that the ratio between signal voltage and noise voltage does not become better by the application of this device.

EXPERIMENTS WITH STEREOPHONIC RECORDS

by K. de BOER.

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In the previously discussed method of stereophonic reproduction two channels must be available for the transmission. When such a reproduction is to be recorded in the form of "stereophonic records" two sound tracks must be traced on the gramophone record which can be scanned simultaneously by two pickups. In the arrangement for practical purposes, in addition to the differences in intensity and time which determine the position of the "sound image", there are additional time differences which result in a gradual or oscillating shift of the sound image. The measures and tolerances are discussed by which these shifts can be kept within the desired limits.

Introduction

In the method of stereophonic reproduction (reproduction which retains a sense of the positions of the various sources of sound), which was recently discussed in this periodical¹⁾, the sound is intercepted at two places in the recording room, conducted along two separate channels and reproduced in the receiving room at two places. The two microphones for the interception may for instance be placed on either side of a sphere ("artificial head"). The reproduction may take place either with two head phones or with two loud speakers which are set up in the manner indicated in *fig. 1*.

In the article mentioned we showed that with such

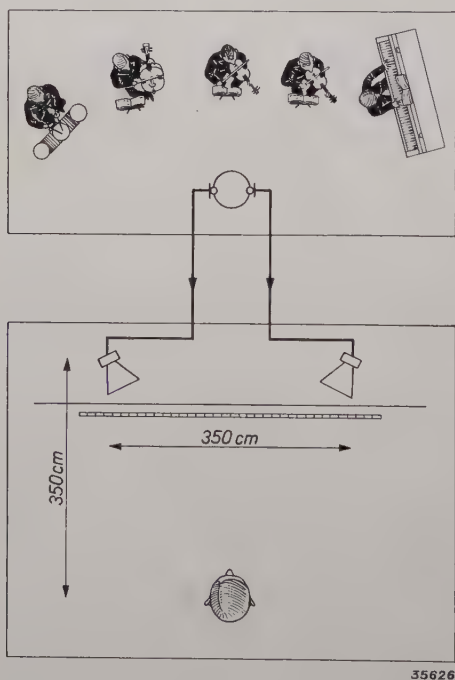


Fig. 1. Scheme of a stereophonic sound transmission. In the recording room (above) are two microphones on either side of a sphere ("artificial head"); two channels to the reproduction room (below); here two loud speakers at left and right in front of the listener. In our experiments the dimensions indicated were used as a rule. On the scale in front of the loud speakers the sound image can be definitely located to within a few centimeters.

an arrangement good stereophonic reproduction is possible. The practical consequences of the requirement that two channels (amplifiers + transmission lines) must be used we did not discuss there. According to the nature of the application of stereophonic reproduction, this requirement is accompanied by entirely different problems — different as to character and degree of importance. In the case of cinemas, one of the most important spheres of application for stereophonic reproduction, the creation of a second channel, which in this case would consist of a second sound track on the film, will offer no fundamental difficulties. In broadcasting the problem is more difficult: two separate channels in the form of two transmitters working on different wave lengths for a single programme will hardly be found available. It may perhaps be found possible to use the side bands on either side of one carrier wave as separate channels. Another possibility of application which we should like to mention is in making an orchestra plastically audible in different rooms of a restaurant or the like at the same time. In this case for the second channel only an extra amplifier and 20 or 30 metres of cable are needed.

For the purpose of experimenting with arrangements for stereophonic reproduction, as well as for its practical use in general, recorded stereophonic music and speech is needed. With this need in view, experiments have been carried out in this laboratory on the recording of stereophonic sound on gramophone records. In the case of such "stereophone records" each of the two contributions to the sound which the microphones receive must be recorded in a separate groove on the disc. One method would be to cut one track on each side of the disc, and upon reproduction to scan both sides simultaneously with two pickups. In order to make this possible the disc would have to be sufficiently stiff, and moreover this method would necessitate the development of entirely new gramophone mechanisms. A

¹⁾ Philips techn. Rev. 5, 107, 1940 (April).

simpler method is to divide the surface of the disc into two zones, the innermost of which contains one sound track and the outer the other. Such records can easily be made with the apparatus for sound recording²⁾ described in this periodical, by mounting two sound track cutters side by side on the transport shaft. Each cutter is then fed from one of the two microphones. In *fig. 2* this arrangement is shown.



Fig. 2. Apparatus for sound recording on discs, designed for stereophonic recording. Two sound track cutters are mounted on the transport shaft, each of which is fed from one of the two microphones and which cut a sound track in the inner and outer zones, respectively, of the disc.

In the article already referred to¹⁾ it is explained that the perception of direction is based upon slight differences in the intensity and moments of arrival of the two sound contributions which are received by the two ears. These differences in intensity and time must be faithfully recorded in the two sound tracks on the stereophone record and must be reproduced upon playing the record with equal fidelity. Due to various causes extra time differences occur between the two sound contributions when the record is played, so that the position of the source of sound observed by the listener (the "sound image") experiences a displacement. It will perhaps be interesting to discuss in somewhat more detail the peculiar difficulties connected with this phenomenon, particularly because of the fact that they form a good illustration of the peculiarities of stereophonic reproduction.

Movement of the scanning needle

In recording, the sound cutter is moved by the transport shaft over the disc in a straight line which coincides with a radius of the disc³⁾.

²⁾ K. de Boer and A. Th. van Urk, A simple apparatus for sound recording, Philips techn. Rev. 4, 106, 1939.

³⁾ Actually, for practical reasons, the needle is made to move on a line which passes several mm away from the axis of the disc. The influence of this on the results in the following discussion may, however, be neglected.

In reproduction, on the other hand, the pickup is fastened to the end of a rotating arm and thus describes an arc of a circle on the disc. This is unavoidable if the lifetime of the disc is to be sufficiently long. In reproduction the spiral grooves of the sound track itself must furnish the guidance for the radial displacement of the needle point, and in order to limit wear and tear of the grooves it is desirable that they should need to exert only an extremely small force on the needle. Guidance of the needle in a straight line, either by means of a rail or one of the jointed constructions for this purpose, familiar in cinema technology, would, however, always be accompanied by fairly large forces of friction — when the play in the position of the pickup is limited to the required degree.

Due to the fact that in reproduction the needle describes a different path on the disc than in the recording, time differences occur. The arm of the pickup is adjusted for both sound tracks so that the needles stand exactly on the straight line of the recording at the beginning and end of the sound track; see *fig. 3*. It may be seen that during the

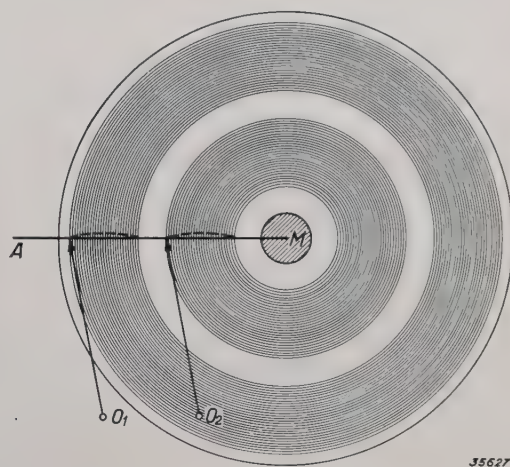


Fig. 3. Stereophone record with sound track in two zones. During recording the two needles moved along the straight line AM , upon reproduction they describe the two arcs of a circle around the pivots O_1 and O_2 of the pickup arms.

playing of the record the two sound contributions experience first a gradually increasing and then a decreasing retardation. This would cause no shift in the sound image if the retardation were equal for both sound contributions. This is, however, not the case, although the deviation of the needle is the same on both tracks (*fig. 3*), due to the difference in speed of the disc at different distances from the centre, the same time differences do not correspond to these equal deviations.

The relative time difference occurring in the two sound contributions can easily be calculated. In the

coordinate system x, y of *fig. 4*, we let the mean radius of the two zones equal L and l , respectively, the width of the zones $2d$ and the length of the arms on which the pick-ups are fastened P and p ,

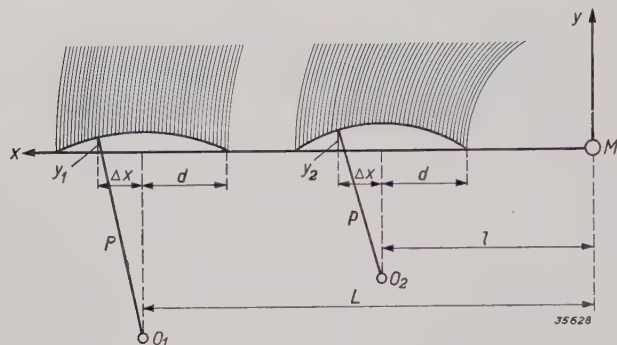


Fig. 4. Geometrical configuration of the paths of the needles in recording and reproduction for the calculation of the relative time differences occurring between the two sound contributions.

respectively. Between the shift Δx of the needle from the middle of the zone and its deviation y_1 or y_2 respectively from the straight recording line, the following relation exists:

$$\Delta x^2 + (y_1 + \sqrt{P^2 - d^2})^2 = P^2,$$

$$\Delta x^2 + (y_2 + \sqrt{p^2 - d^2})^2 = p^2.$$

For sufficiently large values of P and p this can be simplified to

$$y_1 = \frac{d^2 - \Delta x^2}{2P}; y_2 = \frac{d^2 - \Delta x^2}{2p} \dots (1)$$

The speed of the disc at Δx is:

$$\left. \begin{array}{l} \text{in the outer zone } v_1 = 2\pi n(L + \Delta x), \\ \text{in the inner zone } v_2 = 2\pi n(l + \Delta x), \end{array} \right\} \dots (2)$$

where n is the number of revolutions per second of the disc. The retardation of the sound at point Δx is

$$\Delta t_1 = \frac{y_1}{v_1} \text{ resp. } \Delta t_2 = \frac{y_2}{v_2}, \dots (3)$$

thus the relative difference in time, after substituting values from (1) and (2) is:

$$\Delta t = \Delta t_1 - \Delta t_2 = \frac{d^2 - \Delta x^2}{4\pi n} \left[\frac{1}{P(L + \Delta x)} - \frac{1}{p(l + \Delta x)} \right].$$

This expression has a maximum in the neighbourhood of $\Delta x = 0$ (about the middle of the zones). For this point

$$\Delta t_0 = \frac{d^2}{4\pi n} \left(\frac{1}{PL} - \frac{1}{pl} \right) \dots (4)$$

In our experiments we have always worked with the following dimensions, suitable for practical use.

$L = 12.45$ cm, $l = 7.35$ cm, $d = 1.85$ cm; n is ordinarily 78/60 r.p.s. If in the first instance we take for P and p the usual length of 20 cm, then

$$\Delta t_0 = 5.8 \cdot 10^{-4} \text{ sec.}$$

We have seen in the article so often referred to¹⁾ that the angular displacements of the sound image, which are caused by various simultaneous intensity and time differences are additive, and especially that between the time differences and the rotations caused thereby the relation shown in *fig. 5* exists. When the original sound image in the arrangement shown in *fig. 1* was situated exactly in the middle of the scale, then according to *fig. 5a* shift of 46 cm corresponds to the calculated time difference Δt_0 . If for example the gramophone record is of a piece of music played by a small orchestra, the middle instrument would be heard as if moved nearly half a meter from his original position halfway through the performance. This is of course very undesirable. It has, however, been found that a shift of not more than 20 cm may be considered permissible, which means a time difference of 2.4×10^{-4} sec.

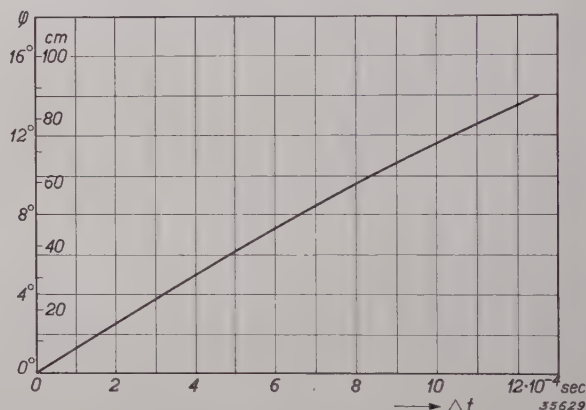


Fig. 5. Angular rotation φ (or shift) of the sound image which is caused by a time difference Δt .

The time difference Δt_0 could be limited to this value by making the equal arms P and p sufficiently long. It follows from equation (4) that Δt_0 is inversely proportional to this length. In our case P and p would have to be made $20 \cdot 5.8/2.4 = 48$ cm long, so that a rather awkward construction would result. A better method is to make the arms P and p of unequal lengths, such that

$$PL = pl \dots (5)$$

Then according to equation (4) $\Delta t_0 = 0$. The relative time difference between the two sound contributions therefore disappears not only at the beginning and end of the sound track but also in the middle: The time difference which can occur

at other intermediate times can be calculated to be $0.4 \cdot 10^{-4}$ sec. at the most. The maximum shift of sound image corresponding to this is about 4 cm and therefore quite harmless.

For the above mentioned dimensions equation (5) becomes

$$P = 0.59 p$$

If the arm P for the outer zone is made 20 cm long, then p must be 34 cm long. In *fig. 6* a photograph of such an arrangement may be seen.

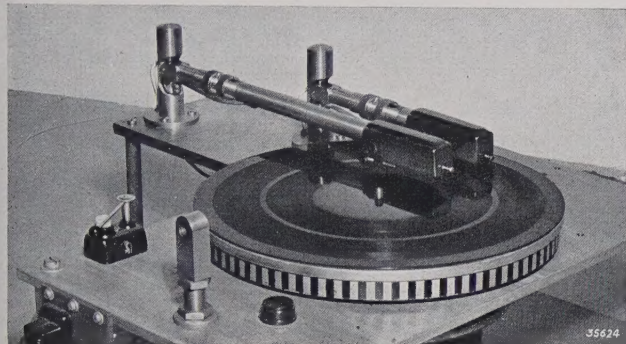


Fig. 6. Arrangement for playing stereophonic records. The arm of the outer pickup is shorter than that of the inner pickup according to a definite relation (equation (5)).

Placing the needles on the record

Another possible cause of extra time differences between the two sound contributions are small errors made in setting the two needles on the disc. They should be set upon corresponding points in the two sound tracks. In order to be able to do this a small radial scratch is made with each cutter beside the sound track at the beginning and end of the recording. Upon reproduction, by adjusting the length of the pick-up arms care must be taken that the needles stand in these scratches. Suppose a deviation of $\pm \varepsilon$ to occur in this setting (*fig. 7*). During the playing of the whole record this deviation will remain unchanged. The time difference between the two sound contributions, assuming the most unfavourable case when $y_1 = \varepsilon$ and $y_2 = -\varepsilon$, is according to equation (3):

$$\Delta t = \varepsilon \left(\frac{1}{v_1} + \frac{1}{v_2} \right).$$

Thus after substituting from equation (2)

$$\Delta t = \frac{\varepsilon}{2\pi n} \left(\frac{1}{L + \Delta x} + \frac{1}{l + \Delta x} \right).$$

It is obvious that during the playing of the record (Δx varies from $+d$ through zero to $-d$) this expression does not pass through a maximum, but increases gradually from an initial value Δt_a to a

final value Δt_e . We may imagine the time difference to be composed of a constant part Δt_a and a part which increases from zero to $\Delta t_{\max} = \Delta t_e - \Delta t_a$. The angular displacement of the sound image due to the constant part Δt_a (the time difference at the beginning of the record) may be neglected. This difference can, thanks to the above-mentioned additivity, simply be compensated by introducing a constant intensity difference between the two sound contributions, by means of the volume controls of the two amplifiers, such that an equal and opposite shift of the sound image is obtained. There thus remains the steadily increasing part of the time difference, which causes a gradually increasing shift of the sound image during the playing of the record. At the end of the record the time difference is:

$$\Delta t_{\max} = \frac{\varepsilon}{2\pi n} \left[\left(\frac{1}{L-d} + \frac{1}{l-d} \right) - \left(\frac{1}{L+d} + \frac{1}{l+d} \right) \right].$$

Substituting the above indicated numerical values for n , L , l and d gives:

$$\Delta t_{\max} = 0.012 \cdot \varepsilon.$$

If we now demand that the final shift of the sound image shall be not more than 20 cm, i.e. that $\Delta t_{\max} = 2.4 \times 10^{-4}$ sec., the value of ε which follows is 0.2 mm. This is therefore the maximum error which may be made in setting each needle on the record.

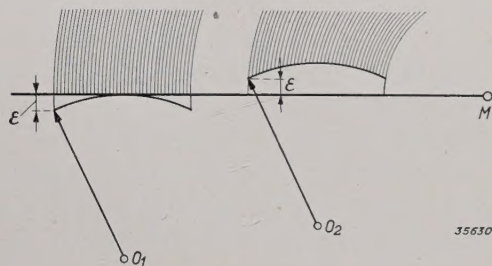


Fig. 7. In setting the needles upon corresponding points on the two sound tracks a slight error ε may occur.

Eccentricity of the gramophone axis

When the hole in the middle of the gramophone record is somewhat larger than the axis of the turntable, the record may be slightly excentric. In ordinary reproduction this has no other consequence than a slight, generally not disturbing rising and falling of the tones. In the case of stereophonic reproduction, however, a new effect occurs, namely an oscillation of the sound image at a frequency n (number of revolutions of the disc). This may be explained as follows. In *fig. 8* the record, which is

placed eccentrically upon the axis, is drawn in two extreme positions. It is of no concern whether this is for recording or reproduction, and we shall only assume for the sake of simplicity that in one of the two processes the record will be exactly centred

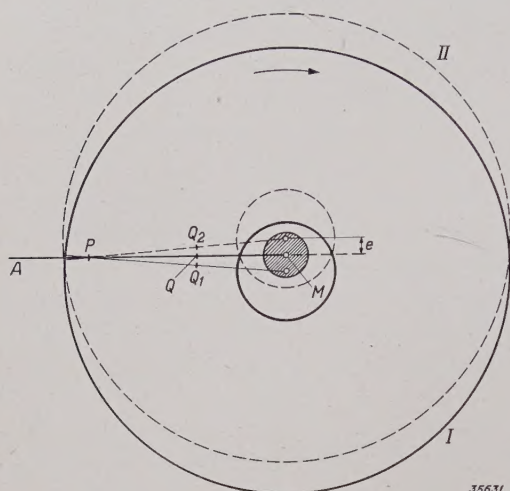


Fig. 8. The axis of the turn table lies in the hole of the disc with an excentricity e . For the sake of simplicity we assume the needles to move along the line AM in recording and playing. At a given moment, for instance, they are at P and Q . In position I of the record the inner pickup should actually be at Q_1 , in position II of the record at Q_2 . The sound of the inner zone in reproduction is therefore periodically slightly behind and ahead, respectively, of that of the outer zone.

and that the needles run exactly along the radial line AM in recording as well as reproduction. Imagine now that the record is in position I and that the outer pick-up is at point P . The corresponding point in the inner zone is Q_1 ; the needle in this zone is, however, at Q , and the sound contribution of the inner zone is therefore somewhat behind. After half a revolution the record is in position II and when the outer pick-up is at P the inner one should be at Q_2 , while actually it is at Q , and thus the sound contribution of the inner zone is ahead. The result is a time difference between the two sound contributions changing its sign periodically, and thus an oscillation of the sound image about an intermediate position.

Experience has shown that such an oscillation when the frequency is greater than $1/3$ c/s, is interpreted as a lack of definition of the sound image, which has a width about equal to twice the amplitude of the motion back and forth. The effect is not disturbing when this amplitude is not greater than about 5 cm, thus the maximum time difference $\Delta t < 0.6 \times 10^{-4}$ sec. From this the permissible eccentricity of the axis can easily be calculated. It follows from fig. 8 that the amplitude of the deviation in position between the two needles amounts to

$$1/1 Q_1 Q_2 = \frac{L - l}{L + \Delta x} \cdot e,$$

where e is the eccentricity (distance between the centres of axis and disc) and the other symbols are the same as above. According to equations (3) and (2) the time difference

$$\Delta t = 1/2 \frac{Q_1 Q_2}{v_2} = \frac{(L - l) e}{2\pi n (L + \Delta x) (l + \Delta x)}.$$

Δt reaches its greatest value at $\Delta x = -d$ (at the end of the record). With the already given numerical values one finds

$$\Delta t_{\max} = 0.0107 \cdot e,$$

thus the permissible eccentricity

$$e = \frac{0.6 \cdot 10^{-4}}{0.0107} = 0.006 \text{ cm.}$$

Since the eccentricity can at the most be equal to half the difference in the diameters of the axis and of the hole in the disc, the lack of definition of the sound image is certainly kept within the desired limits when the tolerance for the diameter of the hole is made 0.1 mm. By a suitable construction of the axis of the turn table it is also possible entirely to suppress the eccentricity and therefore the oscillation of the sound image.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

- 1485:** F. A. Kröger: Luminescence and absorption of solid solutions in the ternary system ZnS-CdS-MnS (*Physica* 7, 92-100, Jan. 1940).

The system of solid solutions ZnS-CdS-MnS exhibits a fundamental absorption region and a system of bands. The latter are characteristic of manganese and practically independent of the composition of the solid solutions. The fundamental absorption region consists of two absorption bands. The first band is found in ZnS and CdS, the second in MnS.

At room temperature all ternary solid solutions exhibit emission in a band which is to be ascribed to the lattice. The wave length of the maximum of these bands depends upon the composition of the solid solutions and changes from blue for pure ZnS to infra red with pure CdS.

At -150°C , in addition to the emission bands described, others are present which are characteristic of manganese.

Unheated ZnS-MnS solid solutions obtained by coprecipitation exhibit photoluminescence in the same emission bands as are observed with phosphors prepared at high temperatures.

- 1486:** F. M. Penning and J. H. A. Moubis: Cathode sputtering in a magnetic field (*Proc. Kon. Ned. Akad. Wet.* 43, 41-56, Jan. 1940).

The sputtering of a metal surface is the result of the freeing of one or more metal atoms by the collision of an ion against the surface. The elementary process can be characterized by the coefficient ϑ_o (V_p), which indicates how many metal atoms are freed by one ion of a given energy V_p (including those which return). For a direct measurement of ϑ_o (V_p) it is necessary that the gas pressure be very low, so that the ions shall not be retarded by collisions with gas atoms and that sputtered metal atoms may not return to the metal surface. Measurements at such low pressures are possible in a self-sustaining gas discharge, if a magnetic field of a certain direction and strength is used with a suitable electrode arrangement. From measurements made, using this device, a value of ϑ_o of 1.7 was found for argon ions and copper, and for argon ions and aluminium a value of 0.7 (both for an ion energy of 500 volts). Preliminary measurements were also carried out for argon and hydrogen ions with nickel

and silver. For $500 < V_p < 1400$ volts ϑ_o was found to be about proportional to V_p , so that a definite energy V_p/ϑ_o is necessary to free one atom. The minimum energy necessary for freeing an atom is the atomic heat of evaporation W . We may therefore define the efficiency of sputtering as $\varepsilon = W/(V_p/\vartheta_o)$. This ε is found to be of the order of one per cent and less, in agreement with previous determinations.

- 1487:** J. F. Schouten: Diffraction of light by sound film of the variable width type (*Physica* 7, 101-121, Feb. 1940).

Upon the diffraction of light by strips of sound film diffraction patterns are obtained which may be considered as two dimensional Fourier analyses of the strip of film. With purely sinusoidal modulation the distribution of intensity in the pattern contains all the Bessel functions of whole order. On a line in the spectrum parallel to the length of the film the spectrum gives the exact Fourier analysis of the sound modulated on the film. Comparison with ordinary optical gratings brings out various properties which are discussed. The broadening of the lines which occurs may be ascribed to the finite length of the film. In conclusion the possibilities for the application of these phenomena are briefly discussed.

- 1488:** M. J. O. Strutt and K. S. Knol: Resistance measurements of iron wire in the frequency region from 10^7 to 3×10^8 c/sec (*Physica* 7, 145-154, Feb. 1940). (Original in German).

The resistances of iron wire have previously been determined in the region from 10^6 to 10^7 c/s. in order to investigate certain anomalies found by others in this region. In this investigation no anomalies were discovered. The measurements described give an extension to 3×10^8 c/s. Three wires of 20-40 microns were used. The method of measurement and the results are described at room temperature as well as at the temperature of liquid oxygen (-183°C). The measurements at room temperature again brought no anomalies to light; the measurements at -183°C exhibited a gradual decrease in the permeability with increasing frequency. With the help of Maxwell's theory it is shown that at room temperature the same change of permeability would be expected at a frequency 5 or 6 times as high. In conclusion the possible causes of this phenomenon are discussed.

- 1489:** J. van Slooten: Input capacitance of a triode oscillator (Wireless Eng. **17**, 13-15, Jan. 1940).

It is shown in a general way that the input capacitance of a triode oscillator with grid condenser and leakage resistance decreases with increasing anode voltage. The value of this change in capacity is calculated and found to be in agreement with the experiments.

- 1490:** H. C. Hamaker and E. J. C. Verwey: The role of the forces between the particles in electrode position and other phenomena (Trans. Far. Soc. **36**, 180-185, Jan. 1940).

The investigation of the formation of a covering layer by electrophoresis from suspensions in organic media exhibited a parallelism between this deposition of a layer and the formation of a sediment by settling. This leads to the assumption that electrodeposition is only a mechanical problem in which the electrical nature of the phenomenon is of secondary importance. The electrical field only provides the force which drives the particles to the electrode and presses them against it.

Assuming this to be the case, the process of deposition is analyzed with the help of potential curves. Two kinds of curves can be used to describe the phenomenon. The formation of a covering layer is discussed in detail in these two cases. They should lead to slightly different properties of the layer, but in the case of the suspension investigated the differences observed are not sufficiently pronounced to distinguish between the theoretical possibilities.

- 1491:** H. C. Hamaker: The influence of particle size on the physical behaviour of colloidal systems (Trans. Far. Soc. **36**, 186-192, Jan. 1940).

It is generally assumed that the difference between suspensions and colloidal solutions is only a difference in size of particle. The size of particle is, to be sure, a very important factor. Many properties of a sol depend upon the relation between forces of different natures which act upon the particles. Each of these forces will change independently with the particle size, so that their relation

will depend to a large extent upon this size. The different forces which play a part in the deposition of a layer and their dependence on particle size are discussed and on the basis of the discussion the behaviour of colloidal systems under the influence of gravity and in a centrifuge is dealt with. It may be expected that observation of the properties of a precipitate obtained by centrifuging will be able to furnish valuable information about the potential curves which hold for sols.

- 1492:** E. J. W. Verwey: Electrical double layer and stability of emulsions (Trans. Far. Soc. **36**, 192-203, Jan. 1940).

A discussion is given of the reason why a stable emulsion can never be obtained without an emulsifier. It is assumed that the boundary surface potential occurs due to the ion distribution equilibrium of electrolytes in the two liquid systems. Since the charge on both sides of the double layer has an extension which is determined by thermal movement, the electrokinetic potential is already lowered thereby. Moreover, this extension usually is so great that the double layer cannot be formed completely in concentrated emulsions or with small droplets. In the case of a double layer, emulsifiers restore the necessary conditions which must exist at the boundary of the liquid and the solid substance in order to obtain the necessary high value of the potential.

- 1493:** H. C. Hamaker: Formation of a deposit by electrophoresis (Trans. Far. Soc. **36**, 279-287, Jan. 1940).

It is possible to form a deposit of the suspended material by electrophoresis from certain organic liquids. This phenomenon is discussed from the experimental point of view. With certain limitations the quantity deposited is proportional to the time, the surface of the electrode, the electric field and the concentration.

At low voltages, short times and too low concentrations, deviations from this simple law are observed. The deviations observed can be understood from theoretical considerations. In conclusion a simple method is indicated of studying the density of the layers, and observations are recorded which were obtained by this method.